Attachment D to
Proto-Power Calculation
97-195
Revision A

REFERENCE 8.1

9.2 WATER SYSTEMS

The auxiliary water systems for the LaSalle County Station are as follows:

a. CSCS equipment cooling water system,

b. station service water system,

c. reactor building closed cooling water system,

d. demineralized water makeup system,

e. potable and sanitary water system,

f. ultimate heat sink,

g. cycled condensate system and refueling water storage facilities,

h. turbine building closed cooling water system (TBCCWS),

i. primary containment chilled water system,

j. station heat recovery system,

k. suppression pool cleanup system, and

l. chemical feed system.

9.2.1 CSCS Equipment Cooling Water System

The function of the core standby cooling system-equipment cooling water system (CSCS-ECWS) is to circulate lake water from the ultimate heat sink for cooling of the residual heat removal (RHR) heat exchangers, diesel-generator coolers, CSCS cubicle area cooling coils, RHR pump seal coolers, and low-pressure core spray (LPCS) pump motor cooling coils. This system also provides a source of emergency makeup water for fuel pool cooling and also provides containment flooding water for post-accident recovery. This CSCS-ECWS system is equivalent in purpose to the essential service water cooling systems at other stations.

9.2.1.1 Design Bases

9.2.1.1.1 Safety Design Bases

a. The system is sized based on the following minimum equipment cooling water flow requirements:

   1. RHR heat exchanger - 7400 gpm

   2. diesel-generator cooler (division 1 and 2 only) - 800 gpm

   3. diesel-generator cooler (division 3) - 650 gpm

REFERENCE 8.1

9.5.4.5 Instrumentation and Controls

Fuel levels in each day tank and storage tank are indicated locally, and storage tank levels are also indicated at each storage tank filling station. Control room alarms annunciate high or low levels in each day tank and low level in each storage tank. All day tank level instruments and diesel-generator transfer pump controls are Seismic Category I and Class 1E. A local pressure indicator is connected to the discharge of each transfer pump to monitor pump discharge head. A local differential pressure indicator is connected across the transfer pump suction strainer to identify a clogged strainer.

Each diesel engine gauge panel includes local gauges for monitoring the following diesel-generator skid-mounted system fuel oil parameters: fuel oil temperature, fuel pump suction strainer inlet and outlet pressure (Divisions 1 and 2 diesel generators only), fuel pump discharge pressure, fuel filter inlet pressure, and fuel filter outlet pressures (for the Division 3 diesel generators, filter inlet and outlet pressure gauges are mounted on the engine and not on the gauge panel). In addition, pressure switches are installed in the skid-mounted systems to annunciate high fuel filter differential pressure for the Divisions 1 and 2 diesel generators and low fuel pump discharge pressure for the Division 3 diesel generators. The entire skid-mounted fuel oil system, including instrumentation, is supplied by the engine manufacturer as a part of the diesel engine.

Each diesel-generator fuel transfer pump is started and stopped automatically by day tank level control switches. The diesel fire pump fuel transfer pump is started manually; however, it is automatically shut down by day tank high level. Elapsed time instrumentation monitors diesel-generator transfer pump running time and, when the diesel engine is operating, pump shutdown time. This instrumentation actuates control room alarm lights if pump running time is excessive or shutdown time is too short to permit remote detection of possible fuel oil leaks at the day tank or diesel generator.

9.5.5 Diesel-Generator Cooling Water System

The function of the diesel-generator cooling water system is to transfer the heat rejected from the engine water jacket, the lube oil cooler and the engine air aftercooler to the CSCS equipment cooling water system (CSCS-ECWS).

9.5.5.1 Design Bases

9.5.5.1.1 Safety Design Bases

Cooling capacity of this system is based on a diesel-generator output of 2860 kW with an environmental temperature of 122° F maximum and a minimum and maximum lake water temperature of 32° F and 100° F, respectively. Total heat transfer by this system is

REFERENCE 8.1

approximately 7.8 x 10^6 Btu/hr per diesel-generator set at rated engine capacity. The diesel cooling water heat exchangers are sized based on operation of 110% of rated load.

High water temperature is alarmed at 200° F and the engine is automatically shut down if the cooling water temperature at the engine outlet exceeds 208° F in order to prevent engine damage due to overheating. This shutdown control is in effect only when the engine is started manually and bypassed when the diesel generator is started automatically during an emergency.

Heaters are installed in the cooling water piping below the lube oil cooler to maintain the engine water and lube oil in a warm standby condition while the engine is not operating; thus increasing the starting reliability of the diesel generator. Natural convection is employed to circulate the warm engine water through the lube oil cooler during standby.

Each system is designed based on Seismic Category I requirements and is protected from tornadoes, missiles, and flooding.

9.5.5.1.2 Power Generation Design Bases

The diesel-generator cooling water system is not required during power generation. Consequently, it possesses no power generation design bases.

9.5.5.2 System Description

Each diesel-generator cooling water system is a separate, independent closed loop system supplied with the diesel generator and located entirely on the diesel-generator skid. It consists of two parallel engine driven centrifugal circulating pumps, a low-pressure expansion tank, an AMOT temperature regulating valve, a lube oil cooler, and the engine cooling water heat exchanger. The expansion tank is fitted with a 7 psig relief cap which also will relieve vacuum. Engine coolant is demineralized water treated with chromate, borate-nitrite, or silicate-nitrite type corrosion inhibitors in accordance with the engine manufacturer's recommendations.

During operation, cooling water at a flow of 1100 gpm per diesel-generator set is circulated by the engine driven pumps through the diesel engine cooling water passages to the lube oil cooler, through the temperature regulating valve, and then to the engine cooling water heat exchanger. See Figure 9.5-5 for additional details.

The engine cooling water heat exchanger is a two-pass shell and tube type heat exchanger having admiralty tubes with a carbon steel water box and shell. Engine cooling water is circulated through the shell side while strained lake water is pumped through the tube side by the CSCS-ECWS (Subsection 9.2.1). Design pressure and temperature is 150 psig and 300° F for both

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Rev: A Page 4 of 5

REFERENCE 8.4

QUESTION 040.92

"In response to Question 040.16 you have provided in section 9.5.5.1.1 a total diesel generator cooling water heat rate of approximately 6.15 million Btu/hr. This heat is rejected in the heat exchanger interfacing with CSCS equipment cooling water system when the diesel generator is operating at rated capacity. Also, in section 9.5.5.2 you mention that the cooling waterflow rate in the diesel engine is 1,100 gpm. It is not clear whether these heat and flow rates are for the total five diesel generators or for a single diesel generator. Please provide the heat and flow rates for each of the five diesel generators. In addition, also provide the design temperature differential((°F) for each diesel engine cooling water when operating at rated capacity."

RESPONSE

The design conditions for each diesel-generator cooling water system are:

Shell side flow	1100 gpm
Design shell side inlet temperature	190° F
Shell side outlet temperature	175° F
Tube side design flow	800 gpm
Tube side inlet temperature	100° F
Tube side outlet temperature	122° F
Heat exchanger design heat removal	8.6 x 10^6 btu/hr
Diesel-generator set cooling requirement	7.8 x 10^6 btu/hr

(The value of 6.15 x 10^6 btu/hr heat removal specified in Subsection 9.5.5.1.1 has been corrected to read 7.8 x 10^6 btu/hr in accordance with the above data).

Attachment E to
Proto-Power Calculation
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Revision A

Shell and Tube Heat Exchanger Input Parameters

		Shell-Side	Tube-Side
Fluid Quantity, Total	gpm	1,099.45	775.61
Inlet Temperature	°F	190.00	100.00
Outlet Temperature	°F	174.40	122.20
Fouling Factor		0.00285	0.00000
Shell Fluid Name			Fresh Water
Tube Fluid Name			Fresh Water
Design Heat Transfer (BTU/hr)			8,600,000
Design Heat Trans Coeff (BTU/hr·ft²·°F)			255.20
Emprical Factor for Outside h			0.780339000
Performance Factor (% Reduction)			0.00
Heat Exchanger Type			TEMA-E
Effective Area (ft^2)			479.00
Area Factor			0.998169790
Area Ratio			
Number of Shells per Unit			1
Shell Minimum Area			0.490000000
Shell Velocity (ft/s)			5.000
Tube Pitch (in)			0.7500
Tube Pitch Type			Triangular
Number of Tube Passes			2
U-Tubes			No
Total Number of Tubes			188
Number of Active Tubes			188
Tube Length (ft)			13.00
Tube Inside Diameter (in)			0.652
Tube Outside Diameter (in)			0.750
Tube Wall Conductivity (BTU/hr·ft·°F)			112.00
Ds, Shell Inside Diameter (in)			0.000
Lbc, Central Baffle Spacing (in)			0.000
Lbi, Inlet Baffle Spacing (in)			0.000
Lbo, Outlet Baffle Spacing (in)			0.000
Dotl, Tube circle diameter (in)			0.000
Bh, Baffle cut height (in)			0.000
Lsb, Diametral difference between Baffle and Shell (in)			0.000
Ltb, Diametral difference between Tube and Baffle (in)			0.000
Nss, Number Sealing Strips			0.000

VENDOR DATA SHEET GIVES <u>TOTAL</u> FOULING
- THEREFORE, SHELL-SIDE IS SET TO TOTAL FOULING AND TUBE-SIDE FOUL IS SET TO 0.

PROTO-HX CALCULATED VALUE @ BENCHMARK CONDITIONS.

DATA SHEET AREA (EFFECTIVE)

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

Vendor Data Sheet - BENCHMARK

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data

Tube Flow (gpm)	775.6
Shell Flow (gpm)	1,099.5
Tube Inlet Temp (°F)	100.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.5E+5
Tube Mass Flow (lbm/hr)	3.88E+5
Heat Transferred (BTU/hr)	8.589E+6
LMTD	71.1
Effective Area (ft²)	479.0

COMPARED TO VENDOR DATA SHEET

Property	Shell-Side	Tube-Side
Velocity (ft/s)	5.15	8.00
Reynold's Number	8.537E+04	6.589E+04
Prandtl Number	2.13	4.00
Bulk Visc (lbm/ft·hr)	0.82	1.47
Skin Visc (lbm/ft·hr)	0.87	1.33
Density (lbm/ft³)	60.53	61.85
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.37

Overall Fouling (hr·ft²·°F/BTU)	0.002850
Shell-Side ho (BTU/hr·ft²·°F)	2,075.6
Tube-Side hi (BTU/hr·ft²·°F)	2,100.5
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9886
U Overall (BTU/hr·ft²·°F)	255.2
Shell Temp In (°F)	190.0
Shell Temp Out (°F)	174.4
Tav Shell (°F)	182.2
Shell Skin Temp (°F)	173.5
Tube Temp In (°F)	100.0
Tube Temp Out (°F)	122.2
Tav Tube (°F)	111.1
Tube Skin Temp (°F)	121.0

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

Commonwealth Edison
Calculation Report for DG01A - DG Jacket Water Cooler
Vendor Design Condition - Adj. Area

Shell and Tube Heat Exchanger Input Parameters

		Shell-Side	Tube-Side
Fluid Quantity, Total	gpm	1,099.45	775.61
Inlet Temperature	°F	190.00	100.00
Outlet Temperature	°F	174.40	122.20
Fouling Factor		0.00285	0.00000

VENDOR DATA SHEET VALUES.

Shell Fluid Name	Fresh Water
Tube Fluid Name	Fresh Water
Design Heat Transfer (BTU/hr)	8,600,000
Design Heat Trans Coeff (BTU/hr·ft²·°F)	255.20
Emprical Factor for Outside h	0.780339000
Performance Factor (% Reduction)	0.00
Heat Exchanger Type	TEMA-E
Effective Area (ft^2)	471.23
Area Factor	0.981978184
Area Ratio	
Number of Shells per Unit	1
Shell Minimum Area	0.490000000
Shell Velocity (ft/s)	5.000
Tube Pitch (in)	0.7500
Tube Pitch Type	Triangular
Number of Tube Passes	2
U-Tubes	No
Total Number of Tubes	188
Number of Active Tubes	188
Tube Length (ft)	13.00
Tube Inside Diameter (in)	0.652
Tube Outside Diameter (in)	0.750
Tube Wall Conductivity (BTU/hr·ft·°F)	112.00
Ds, Shell Inside Diameter (in)	0.000
Lbc, Central Baffle Spacing (in)	0.000
Lbi, Inlet Baffle Spacing (in)	0.000
Lbo, Outlet Baffle Spacing (in)	0.000
Dotl, Tube circle diameter (in)	0.000
Bh, Baffle cut height (in)	0.000
Lsb, Diametral difference between Baffle and Shell (in)	0.000
Ltb, Diametral difference between Tube and Baffle (in)	0.000
Nss, Number Sealing Strips	0.000

CALCULATED IN SECTION 3.2

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12:22:07      PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)      06/29/98
                          Commonwealth Edison
          Calculation Report for DG01A - DG Jacket Water Cooler
                 Vendor Design Condition - Adj. Area
                      Calculation Specifications
                Constant Inlet Temperature Method Was Used
                Extrapolation Was to User Specified Conditions
                Design Fouling Factors Were Used

              Test Data                            Extrapolation Data
Data Date                               Tube Flow (gpm)                  775.6
Shell Flow (gpm)                        Shell Flow (gpm)               1,099.5
Shell Temp In (°F)                      Tube Inlet Temp (°F)             100.0
Shell Temp Out (°F)                     Shell Inlet Temp (°F)            190.0
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)
                      Fouling Calculation Results

Shell Mass Flow (lbm/hr)                U Overall (BTU/hr·ft²·°F)
Tube Mass Flow (lbm/hr)                 Shell-Side ho (BTU/hr·ft²·°F)
                                        Tube-Side hi (BTU/hr·ft²·°F)
Heat Transferred (BTU/hr)               1/Wall Resis (BTU/hr·ft²·°F)
LMTD                                    LMTD Correction Factor
Effective Area (ft²)
                                        Overall Fouling (hr·ft²·°F/BTU)
Property           Shell-Side   Tube-Side
Velocity (ft/s)                         Shell Temp In (°F)
Reynold's Number                        Shell Temp Out (°F)
Prandtl Number                          Tav Shell (°F)
Bulk Visc (lbm/ft·hr)                   Shell Skin Temp (°F)
Skin Visc (lbm/ft·hr)                   Tube Temp In (°F)
Density (lbm/ft³)                       Tube Temp Out (°F)
Cp (BTU/lbm·°F)                         Tav Tube (°F)
K (BTU/hr·ft·°F)                        Tube Skin Temp (°F)

                   Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)          5.5E+5   Overall Fouling (hr·ft²·°F/BTU)  0.002850
Tube Mass Flow (lbm/hr)          3.88E+5   Shell-Side ho (BTU/hr·ft²·°F)     2,076.0
                                           Tube-Side hi (BTU/hr·ft²·°F)      2,099.0
Heat Transferred (BTU/hr)       8.481E+6   1/Wall Resis (BTU/hr·ft²·°F)     25,594.8
LMTD                                71.3   LMTD Correction Factor             0.9889
Effective Area (ft²)               471.2
                                           U Overall (BTU/hr·ft²·°F)           255.2
Property           Shell-Side   Tube-Side
Velocity (ft/s)          5.15        8.00  Shell Temp In (°F)                  190.0
Reynold's Number    8.543E+04   6.580E+04  Shell Temp Out (°F)                 174.6
Prandtl Number           2.13        4.00  Tav Shell (°F)                      182.3
Bulk Visc (lbm/ft·hr)    0.82        1.47  Shell Skin Temp (°F)                173.5
Skin Visc (lbm/ft·hr)    0.87        1.34  Tube Temp In (°F)                   100.0
Density (lbm/ft³)       60.52       61.85  Tube Temp Out (°F)                  121.9
Cp (BTU/lbm·°F)          1.00        1.00  Tav Tube (°F)                       110.9
K (BTU/hr·ft·°F)         0.39        0.37  Tube Skin Temp (°F)                 120.9

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie
```

Shell and Tube Heat Exchanger Input Parameters

		Shell-Side	Tube-Side
Fluid Quantity, Total	gpm	1,099.45	775.61
Inlet Temperature	°F	190.00	100.00
Outlet Temperature	°F	174.40	122.20
Fouling Factor		0.00285	0.00000

Shell Fluid Name	Fresh Water
Tube Fluid Name	Fresh Water
Design Heat Transfer (BTU/hr)	8,600,000
Design Heat Trans Coeff (BTU/hr·ft^2·°F)	255.20
Emprical Factor for Outside h	0.780339000
Performance Factor (% Reduction)	0.00
Heat Exchanger Type	TEMA-E
Effective Area (ft^2)	471.23
Area Factor	0.981978184
Area Ratio	
Number of Shells per Unit	1
Shell Minimum Area	0.490000000
Shell Velocity (ft/s)	5.000
Tube Pitch (in)	0.7500
Tube Pitch Type	Triangular
Number of Tube Passes	2
U-Tubes	No
Total Number of Tubes	188
Number of Active Tubes	188
Tube Length (ft)	13.00
Tube Inside Diameter (in)	0.652
Tube Outside Diameter (in)	0.750
Tube Wall Conductivity (BTU/hr·ft·°F)	112.00
Ds, Shell Inside Diameter (in)	0.000
Lbc, Central Baffle Spacing (in)	0.000
Lbi, Inlet Baffle Spacing (in)	0.000
Lbo, Outlet Baffle Spacing (in)	0.000
Dotl, Tube circle diameter (in)	0.000
Bh, Baffle cut height (in)	0.000
Lsb, Diametral difference between Baffle and Shell (in)	0.000
Ltb, Diametral difference between Tube and Baffle (in)	0.000
Nss, Number Sealing Strips	0.000

12:26:44 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

Adj. Area - LSCS Ref. Conditions

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data

Tube Flow (gpm)	795.3
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	100.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	3.978E+5
Heat Transferred (BTU/hr)	8.484E+6
LMTD	71.3
Effective Area (ft²)	471.2

LESS THAN
REF. COND.
REQUIRED
HEATRATE

Overall Fouling (hr·ft²·°F/BTU)	0.002850
Shell-Side ho (BTU/hr·ft²·°F)	2,034.1
Tube-Side hi (BTU/hr·ft²·°F)	2,138.0
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9889
U Overall (BTU/hr·ft²·°F)	255.2

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	8.20
Reynold's Number	8.257E+04	6.728E+04
Prandtl Number	2.14	4.01
Bulk Visc (lbm/ft·hr)	0.82	1.47
Skin Visc (lbm/ft·hr)	0.88	1.34
Density (lbm/ft³)	60.53	61.85
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.37

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	174.1
Tav Shell (°F)	182.1
Shell Skin Temp (°F)	173.1
Tube Temp In (°F)	100.0
Tube Temp Out (°F)	121.4
Tav Tube (°F)	110.7
Tube Skin Temp (°F)	120.5

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

Calculation Report for DG01A - DG Jacket Water Cooler
Reference Condition - Fouling Limit

Shell and Tube Heat Exchanger Input Parameters

		Shell-Side	Tube-Side
Fluid Quantity, Total	gpm	1,099.45	775.61
Inlet Temperature	°F	190.00	100.00
Outlet Temperature	°F	174.40	122.20
Fouling Factor		0.00285	0.00000

FOULING INPUT MODE USED IN FOLLOWING CALCULATION

Shell Fluid Name	Fresh Water
Tube Fluid Name	Fresh Water
Design Heat Transfer (BTU/hr)	8,600,000
Design Heat Trans Coeff (BTU/hr·ft²·°F)	255.20
Emprical Factor for Outside h	0.780339000
Performance Factor (% Reduction)	0.00
Heat Exchanger Type	TEMA-E
Effective Area (ft^2)	471.23
Area Factor	0.981978184
Area Ratio	
Number of Shells per Unit	1
Shell Minimum Area	0.490000000
Shell Velocity (ft/s)	5.000
Tube Pitch (in)	0.7500
Tube Pitch Type	Triangular
Number of Tube Passes	2
U-Tubes	No
Total Number of Tubes	188
Number of Active Tubes	188
Tube Length (ft)	13.00
Tube Inside Diameter (in)	0.652
Tube Outside Diameter (in)	0.750
Tube Wall Conductivity (BTU/hr·ft·°F)	112.00
Ds, Shell Inside Diameter (in)	0.000
Lbc, Central Baffle Spacing (in)	0.000
Lbi, Inlet Baffle Spacing (in)	0.000
Lbo, Outlet Baffle Spacing (in)	0.000
Dotl, Tube circle diameter (in)	0.000
Bh, Baffle cut height (in)	0.000
Lsb, Diametral difference between Baffle and Shell (in)	0.000
Ltb, Diametral difference between Tube and Baffle (in)	0.000
Nss, Number Sealing Strips	0.000

12:29:43 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison
Calculation Report for DG01A - DG Jacket Water Cooler
Reference Condition - Fouling Limit

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Fouling Was Input by User — ITERATION USING FOULING UNTIL REF. CONDITION HEAT RATE IS REACHED

Test Data		Extrapolation Data	
Data Date		Tube Flow (gpm)	795.3
Shell Flow (gpm)		Shell Flow (gpm)	1,064.5
Shell Temp In (°F)		Tube Inlet Temp (°F)	100.0
Shell Temp Out (°F)		Shell Inlet Temp (°F)	190.0
Tube Flow (gpm)			
Tube Temp In (°F)			
Tube Temp Out (°F)		Input Fouling Factor	0.002782

Fouling Calculation Results

Shell Mass Flow (lbm/hr)		U Overall (BTU/hr·ft²·°F)	
Tube Mass Flow (lbm/hr)		Shell-Side ho (BTU/hr·ft²·°F)	
		Tube-Side hi (BTU/hr·ft²·°F)	
Heat Transferred (BTU/hr)		1/Wall Resis (BTU/hr·ft²·°F)	
LMTD		LMTD Correction Factor	
Effective Area (ft²)			
		Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side		
Velocity (ft/s)			Shell Temp In (°F)	
Reynold's Number			Shell Temp Out (°F)	
Prandtl Number			Tav Shell (°F)	
Bulk Visc (lbm/ft·hr)			Shell Skin Temp (°F)	
Skin Visc (lbm/ft·hr)			Tube Temp In (°F)	
Density (lbm/ft³)			Tube Temp Out (°F)	
Cp (BTU/lbm·°F)			Tav Tube (°F)	
K (BTU/hr·ft·°F)			Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5	Overall Fouling (hr·ft²·°F/BTU)	0.002782
Tube Mass Flow (lbm/hr)	3.978E+5	Shell-Side ho (BTU/hr·ft²·°F)	2,033.3
		Tube-Side hi (BTU/hr·ft²·°F)	2,140.0
Heat Transferred (BTU/hr)	8.6E+6	1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD	71.1	LMTD Correction Factor	0.9885
Effective Area (ft²)	471.2		
		U Overall (BTU/hr·ft²·°F)	259.7

REFERENCE HEAT RATE

ADJUSTED OVERALL FOULING FACTOR

Property	Shell-Side	Tube-Side		
Velocity (ft/s)	4.99	8.20	Shell Temp In (°F)	190.0
Reynold's Number	8.251E+04	6.738E+04	Shell Temp Out (°F)	173.9
Prandtl Number	2.14	4.01	Tav Shell (°F)	181.9
Bulk Visc (lbm/ft·hr)	0.82	1.47	Shell Skin Temp (°F)	172.9
Skin Visc (lbm/ft·hr)	0.88	1.34	Tube Temp In (°F)	100.0
Density (lbm/ft³)	60.53	61.85	Tube Temp Out (°F)	121.6
Cp (BTU/lbm·°F)	1.00	1.00	Tav Tube (°F)	110.8
K (BTU/hr·ft·°F)	0.39	0.37	Tube Skin Temp (°F)	120.8

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

Commonwealth Edison
Calculation Report for DG01A - DG Jacket Water Cooler
**** FINAL MODEL ****

Shell and Tube Heat Exchanger Input Parameters

		Shell-Side	Tube-Side
Fluid Quantity, Total	gpm	1,099.45	775.61
Inlet Temperature	°F	190.00	100.00
Outlet Temperature	°F	174.40	122.20
Fouling Factor		0.00278	0.00000

REDUCED OVERALL FOULING SECTION 6.2

Shell Fluid Name	Fresh Water
Tube Fluid Name	Fresh Water
Design Heat Transfer (BTU/hr)	8,600,000
Design Heat Trans Coeff (BTU/hr·ft²·°F)	255.20
Emprical Factor for Outside h	0.780339000
Performance Factor (% Reduction)	0.00
Heat Exchanger Type	TEMA-E
Effective Area (ft^2)	471.23
Area Factor	0.981978184
Area Ratio	
Number of Shells per Unit	1
Shell Minimum Area	0.490000000
Shell Velocity (ft/s)	5.000
Tube Pitch (in)	0.7500
Tube Pitch Type	Triangular
Number of Tube Passes	2
U-Tubes	No
Total Number of Tubes	188
Number of Active Tubes	188
Tube Length (ft)	13.00
Tube Inside Diameter (in)	0.652
Tube Outside Diameter (in)	0.750
Tube Wall Conductivity (BTU/hr·ft·°F)	112.00
Ds, Shell Inside Diameter (in)	0.000
Lbc, Central Baffle Spacing (in)	0.000
Lbi, Inlet Baffle Spacing (in)	0.000
Lbo, Outlet Baffle Spacing (in)	0.000
Dotl, Tube circle diameter (in)	0.000
Bh, Baffle cut height (in)	0.000
Lsb, Diametral difference between Baffle and Shell (in)	0.000
Ltb, Diametral difference between Tube and Baffle (in)	0.000
Nss, Number Sealing Strips	0.000

ADJUSTED AREA SECTION 3.2

12:31:13 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

**** FINAL MODEL ****

Calculation Specifications

Constant Inlet Temperature Method Was Used

Extrapolation Was to User Specified Conditions

Design Fouling Factors Were Used — ADJUSTED FOULING NOW DESIGN FOULING FACTOR IN PROTO-HX MODEL

Test Data

Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data

Tube Flow (gpm)	795.3
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	100.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	3.978E+5
Heat Transferred (BTU/hr)	8.6E+6
LMTD	71.1
Effective Area (ft²)	471.2

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,033.3
Tube-Side hi (BTU/hr·ft²·°F)	2,140.0
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9885
U Overall (BTU/hr·ft²·°F)	259.7

ADJUSTED FOULING

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	8.20
Reynold's Number	8.251E+04	6.738E+04
Prandtl Number	2.14	4.01
Bulk Visc (lbm/ft·hr)	0.82	1.47
Skin Visc (lbm/ft·hr)	0.88	1.34
Density (lbm/ft³)	60.53	61.85
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.37

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	173.9
Tav Shell (°F)	181.9
Shell Skin Temp (°F)	172.9
Tube Temp In (°F)	100.0
Tube Temp Out (°F)	121.6
Tav Tube (°F)	110.8
Tube Skin Temp (°F)	120.8

** Reynolds Number Outside Range of Equation Applicability

!! With Minimum Fouling The Test Heat Load Could Not Be Achie

Commonwealth Edison
Calculation Report for DG01A - DG Jacket Water Cooler
FINAL MODEL- CLEAN (0 Fouling)

Shell and Tube Heat Exchanger Input Parameters

		Shell-Side	Tube-Side
Fluid Quantity, Total	gpm	1,099.45	775.61
Inlet Temperature	°F	190.00	100.00
Outlet Temperature	°F	174.40	122.20
Fouling Factor		0.00278	0.00000

Shell Fluid Name	Fresh Water
Tube Fluid Name	Fresh Water
Design Heat Transfer (BTU/hr)	8,600,000
Design Heat Trans Coeff (BTU/hr·ft²·°F)	255.20
Emprical Factor for Outside h	0.780339000
Performance Factor (% Reduction)	0.00
Heat Exchanger Type	TEMA-E
Effective Area (ft^2)	471.23
Area Factor	0.981978184
Area Ratio	
Number of Shells per Unit	1
Shell Minimum Area	0.490000000
Shell Velocity (ft/s)	5.000
Tube Pitch (in)	0.7500
Tube Pitch Type	Triangular
Number of Tube Passes	2
U-Tubes	No
Total Number of Tubes	188
Number of Active Tubes	188
Tube Length (ft)	13.00
Tube Inside Diameter (in)	0.652
Tube Outside Diameter (in)	0.750
Tube Wall Conductivity (BTU/hr·ft·°F)	112.00
Ds, Shell Inside Diameter (in)	0.000
Lbc, Central Baffle Spacing (in)	0.000
Lbi, Inlet Baffle Spacing (in)	0.000
Lbo, Outlet Baffle Spacing (in)	0.000
Dotl, Tube circle diameter (in)	0.000
Bh, Baffle cut height (in)	0.000
Lsb, Diametral difference between Baffle and Shell (in)	0.000
Ltb, Diametral difference between Tube and Baffle (in)	0.000
Nss, Number Sealing Strips	0.000

12:32:54 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

FINAL MODEL- CLEAN (0 Fouling)

Calculation Specifications

Constant Inlet Temperature Method Was Used

Extrapolation Was to User Specified Conditions

Fouling Was Input by User

0 FOULING FOR "CLEAN" Hx. Analysis.

Test Data	
Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data	
Tube Flow (gpm)	795.3
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	100.0
Shell Inlet Temp (°F)	190.0
Input Fouling Factor	0.000000

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

CLEAN HEAT RATE

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	3.978E+5
Heat Transferred (BTU/hr)	1.885E+7
LMTD	48.3
Effective Area (ft²)	471.2

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.97	8.22
Reynold's Number	7.721E+04	7.626E+04
Prandtl Number	2.29	3.50
Bulk Visc (lbm/ft·hr)	0.88	1.30
Skin Visc (lbm/ft·hr)	1.05	1.07
Density (lbm/ft³)	60.74	61.65
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.38	0.37

"CLEAN"

Overall Fouling (hr·ft²·°F/BTU)	0.000000
Shell-Side ho (BTU/hr·ft²·°F)	1,957.5
Tube-Side hi (BTU/hr·ft²·°F)	2,318.4
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.8656
U Overall (BTU/hr·ft²·°F)	955.9
Shell Temp In (°F)	190.0
Shell Temp Out (°F)	154.6
Tav Shell (°F)	172.3
Shell Skin Temp (°F)	148.6
Tube Temp In (°F)	100.0
Tube Temp Out (°F)	147.4
Tav Tube (°F)	123.7
Tube Skin Temp (°F)	146.8

** Reynolds Number Outside Range of Equation Applicability

!! With Minimum Fouling The Test Heat Load Could Not Be Achie

Attachment F to
Proto-Power Calculation
97-195
Revision A

15:49:57 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

Tube-side Fouling = 0.0000

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Fouling Was Input by User

Test Data		Extrapolation Data	
Data Date		Tube Flow (gpm)	795.3
Shell Flow (gpm)		Shell Flow (gpm)	1,064.5
Shell Temp In (°F)		Tube Inlet Temp (°F)	100.0
Shell Temp Out (°F)		Shell Inlet Temp (°F)	190.0
Tube Flow (gpm)			
Tube Temp In (°F)			
Tube Temp Out (°F)		Input Fouling Factor	0.000500

Fouling Calculation Results

Shell Mass Flow (lbm/hr)		U Overall (BTU/hr·ft²·°F)	
Tube Mass Flow (lbm/hr)		Shell-Side ho (BTU/hr·ft²·°F)	
		Tube-Side hi (BTU/hr·ft²·°F)	
Heat Transferred (BTU/hr)		1/Wall Resis (BTU/hr·ft²·°F)	
LMTD		LMTD Correction Factor	
Effective Area (ft²)			
		Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side		
Velocity (ft/s)			Shell Temp In (°F)	
Reynold's Number			Shell Temp Out (°F)	
Prandtl Number			Tav Shell (°F)	
Bulk Visc (lbm/ft·hr)			Shell Skin Temp (°F)	
Skin Visc (lbm/ft·hr)			Tube Temp In (°F)	
Density (lbm/ft³)			Tube Temp Out (°F)	
Cp (BTU/lbm·°F)			Tav Tube (°F)	
K (BTU/hr·ft·°F)			Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5	Overall Fouling (hr·ft²·°F/BTU)	0.000500
Tube Mass Flow (lbm/hr)	3.978E+5	Shell-Side ho (BTU/hr·ft²·°F)	1,983.9
		Tube-Side hi (BTU/hr·ft²·°F)	2,261.9
Heat Transferred (BTU/hr)	1.57E+7	1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD	55.4	LMTD Correction Factor	0.9332
Effective Area (ft²)	471.2		
		U Overall (BTU/hr·ft²·°F)	644.5

Property	Shell-Side	Tube-Side		
Velocity (ft/s)	4.98	8.22	Shell Temp In (°F)	190.0
Reynold's Number	7.883E+04	7.349E+04	Shell Temp Out (°F)	160.6
Prandtl Number	2.24	3.64	Tav Shell (°F)	175.3
Bulk Visc (lbm/ft·hr)	0.86	1.35	Shell Skin Temp (°F)	157.2
Skin Visc (lbm/ft·hr)	0.98	1.15	Tube Temp In (°F)	100.0
Density (lbm/ft³)	60.68	61.72	Tube Temp Out (°F)	139.5
Cp (BTU/lbm·°F)	1.00	1.00	Tav Tube (°F)	119.8
K (BTU/hr·ft·°F)	0.39	0.37	Tube Skin Temp (°F)	138.0

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

15:51:47 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

Tube-side Fouling = 0.0005

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Fouling Was Input by User

Test Data		Extrapolation Data	
Data Date		Tube Flow (gpm)	795.3
Shell Flow (gpm)		Shell Flow (gpm)	1,064.5
Shell Temp In (°F)		Tube Inlet Temp (°F)	100.0
Shell Temp Out (°F)		Shell Inlet Temp (°F)	190.0
Tube Flow (gpm)			
Tube Temp In (°F)			
Tube Temp Out (°F)		Input Fouling Factor	0.001075

Fouling Calculation Results

Shell Mass Flow (lbm/hr)		U Overall (BTU/hr·ft²·°F)	
Tube Mass Flow (lbm/hr)		Shell-Side ho (BTU/hr·ft²·°F)	
		Tube-Side hi (BTU/hr·ft²·°F)	
Heat Transferred (BTU/hr)		1/Wall Resis (BTU/hr·ft²·°F)	
LMTD		LMTD Correction Factor	
Effective Area (ft²)			
		Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5	Overall Fouling (hr·ft²·°F/BTU)	0.001075
Tube Mass Flow (lbm/hr)	3.978E+5	Shell-Side ho (BTU/hr·ft²·°F)	2,003.3
		Tube-Side hi (BTU/hr·ft²·°F)	2,216.1
Heat Transferred (BTU/hr)	1.304E+7	1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD	61.3	LMTD Correction Factor	0.9633
Effective Area (ft²)	471.2		
		U Overall (BTU/hr·ft²·°F)	469.0

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.98	8.21
Reynold's Number	8.020E+04	7.118E+04
Prandtl Number	2.20	3.77
Bulk Visc (lbm/ft·hr)	0.85	1.39
Skin Visc (lbm/ft·hr)	0.94	1.21
Density (lbm/ft³)	60.62	61.77
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.37

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	165.6
Tav Shell (°F)	177.8
Shell Skin Temp (°F)	163.4
Tube Temp In (°F)	100.0
Tube Temp Out (°F)	132.8
Tav Tube (°F)	116.4
Tube Skin Temp (°F)	131.4

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

15:53:34 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison
Calculation Report for DG01A - DG Jacket Water Cooler
Tube-side Fouling = 0.0010

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Fouling Was Input by User

Test Data

Data Date
Shell Flow (gpm)
Shell Temp In (°F)
Shell Temp Out (°F)
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)

Extrapolation Data

Tube Flow (gpm)	795.3
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	100.0
Shell Inlet Temp (°F)	190.0
Input Fouling Factor	0.001650

Fouling Calculation Results

Shell Mass Flow (lbm/hr)
Tube Mass Flow (lbm/hr)

Heat Transferred (BTU/hr)
LMTD
Effective Area (ft²)

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

U Overall (BTU/hr·ft²·°F)
Shell-Side ho (BTU/hr·ft²·°F)
Tube-Side hi (BTU/hr·ft²·°F)
1/Wall Resis (BTU/hr·ft²·°F)
LMTD Correction Factor

Overall Fouling (hr·ft²·°F/BTU)

Shell Temp In (°F)
Shell Temp Out (°F)
Tav Shell (°F)
Shell Skin Temp (°F)
Tube Temp In (°F)
Tube Temp Out (°F)
Tav Tube (°F)
Tube Skin Temp (°F)

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	3.978E+5
Heat Transferred (BTU/hr)	1.112E+7
LMTD	65.5
Effective Area (ft²)	471.2

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.98	8.20
Reynold's Number	8.120E+04	6.953E+04
Prandtl Number	2.17	3.87
Bulk Visc (lbm/ft·hr)	0.84	1.43
Skin Visc (lbm/ft·hr)	0.91	1.27
Density (lbm/ft³)	60.58	61.80
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.37

Overall Fouling (hr·ft²·°F/BTU)	0.001650
Shell-Side ho (BTU/hr·ft²·°F)	2,016.5
Tube-Side hi (BTU/hr·ft²·°F)	2,183.2
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9770
U Overall (BTU/hr·ft²·°F)	368.8
Shell Temp In (°F)	190.0
Shell Temp Out (°F)	169.2
Tav Shell (°F)	179.6
Shell Skin Temp (°F)	167.6
Tube Temp In (°F)	100.0
Tube Temp Out (°F)	128.0
Tav Tube (°F)	114.0
Tube Skin Temp (°F)	126.7

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

15:54:32 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

Tube-side Fouling = 0.0015

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Fouling Was Input by User

Test Data	
Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data	
Tube Flow (gpm)	795.3
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	100.0
Shell Inlet Temp (°F)	190.0
Input Fouling Factor	0.002225

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	3.978E+5
Heat Transferred (BTU/hr)	9.683E+6
LMTD	68.7
Effective Area (ft²)	471.2

Overall Fouling (hr·ft²·°F/BTU)	0.002225
Shell-Side ho (BTU/hr·ft²·°F)	2,026.2
Tube-Side hi (BTU/hr·ft²·°F)	2,158.6
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9842
U Overall (BTU/hr·ft²·°F)	303.9

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	8.20
Reynold's Number	8.194E+04	6.830E+04
Prandtl Number	2.15	3.95
Bulk Visc (lbm/ft·hr)	0.83	1.45
Skin Visc (lbm/ft·hr)	0.89	1.31
Density (lbm/ft³)	60.55	61.83
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.37

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	171.9
Tav Shell (°F)	180.9
Shell Skin Temp (°F)	170.6
Tube Temp In (°F)	100.0
Tube Temp Out (°F)	124.4
Tav Tube (°F)	112.2
Tube Skin Temp (°F)	123.3

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

15:55:33 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

Tube-side Fouling = 0.001984 (LIMIT)

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Fouling Was Input by User

Test Data	
Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data	
Tube Flow (gpm)	795.3
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	100.0
Shell Inlet Temp (°F)	190.0
Input Fouling Factor	0.002782

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	3.978E+5
Heat Transferred (BTU/hr)	8.6E+6
LMTD	71.1
Effective Area (ft²)	471.2

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,033.3
Tube-Side hi (BTU/hr·ft²·°F)	2,140.0
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9885
U Overall (BTU/hr·ft²·°F)	259.7

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	8.20
Reynold's Number	8.251E+04	6.738E+04
Prandtl Number	2.14	4.01
Bulk Visc (lbm/ft·hr)	0.82	1.47
Skin Visc (lbm/ft·hr)	0.88	1.34
Density (lbm/ft³)	60.53	61.85
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.37

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	173.9
Tav Shell (°F)	181.9
Shell Skin Temp (°F)	172.9
Tube Temp In (°F)	100.0
Tube Temp Out (°F)	121.6
Tav Tube (°F)	110.8
Tube Skin Temp (°F)	120.8

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

Attachment G to
Proto-Power Calculation
97-195
Revision A

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 35°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date
Shell Flow (gpm)
Shell Temp In (°F)
Shell Temp Out (°F)
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)

Extrapolation Data

Tube Flow (gpm)	193.5
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	35.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)
Tube Mass Flow (lbm/hr)

Heat Transferred (BTU/hr)
LMTD
Effective Area (ft²)

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

U Overall (BTU/hr·ft²·°F)
Shell-Side ho (BTU/hr·ft²·°F)
Tube-Side hi (BTU/hr·ft²·°F)
1/Wall Resis (BTU/hr·ft²·°F)
LMTD Correction Factor

Overall Fouling (hr·ft²·°F/BTU)

Shell Temp In (°F)
Shell Temp Out (°F)
Tav Shell (°F)
Shell Skin Temp (°F)
Tube Temp In (°F)
Tube Temp Out (°F)
Tav Tube (°F)
Tube Skin Temp (°F)

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	9.68E+4
Heat Transferred (BTU/hr)	8.6E+6
LMTD	98.1
Effective Area (ft²)	471.2

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	1.98
Reynold's Number	8.251E+04	1.155E+04
Prandtl Number	2.14	5.90
Bulk Visc (lbm/ft·hr)	0.82	2.09
Skin Visc (lbm/ft·hr)	0.88	1.39
Density (lbm/ft³)	60.53	62.22
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.35

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,032.2
Tube-Side hi (BTU/hr·ft²·°F)	599.1
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9740
U Overall (BTU/hr·ft²·°F)	191.1
Shell Temp In (°F)	190.0
Shell Temp Out (°F)	173.9
Tav Shell (°F)	181.9
Shell Skin Temp (°F)	172.3
Tube Temp In (°F)	35.0
Tube Temp Out (°F)	123.9
Tav Tube (°F)	79.4
Tube Skin Temp (°F)	117.0

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

09:28:13 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 40°F

Calculation Specifications

Constant Inlet Temperature Method Was Used

Extrapolation Was to User Specified Conditions

Design Fouling Factors Were Used

Test Data

Data Date

Shell Flow (gpm)

Shell Temp In (°F)

Shell Temp Out (°F)

Tube Flow (gpm)

Tube Temp In (°F)

Tube Temp Out (°F)

Extrapolation Data

Tube Flow (gpm)	204.8
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	40.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)

Tube Mass Flow (lbm/hr)

Heat Transferred (BTU/hr)

LMTD

Effective Area (ft²)

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

U Overall (BTU/hr·ft²·°F)

Shell-Side ho (BTU/hr·ft²·°F)

Tube-Side hi (BTU/hr·ft²·°F)

1/Wall Resis (BTU/hr·ft²·°F)

LMTD Correction Factor

Overall Fouling (hr·ft²·°F/BTU)

Shell Temp In (°F)

Shell Temp Out (°F)

Tav Shell (°F)

Shell Skin Temp (°F)

Tube Temp In (°F)

Tube Temp Out (°F)

Tav Tube (°F)

Tube Skin Temp (°F)

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	1.024E+5
Heat Transferred (BTU/hr)	8.6E+6
LMTD	96.0
Effective Area (ft²)	471.2

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	2.10
Reynold's Number	8.251E+04	1.261E+04
Prandtl Number	2.14	5.70
Bulk Visc (lbm/ft·hr)	0.82	2.02
Skin Visc (lbm/ft·hr)	0.88	1.38
Density (lbm/ft³)	60.53	62.20
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.36

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,032.3
Tube-Side hi (BTU/hr·ft²·°F)	634.9
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9744
U Overall (BTU/hr·ft²·°F)	195.1
Shell Temp In (°F)	190.0
Shell Temp Out (°F)	173.9
Tav Shell (°F)	181.9
Shell Skin Temp (°F)	172.3
Tube Temp In (°F)	40.0
Tube Temp Out (°F)	124.0
Tav Tube (°F)	82.0
Tube Skin Temp (°F)	117.3

** Reynolds Number Outside Range of Equation Applicability

!! With Minimum Fouling The Test Heat Load Could Not Be Achie

09:23:51 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 50°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data	
Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data	
Tube Flow (gpm)	232.2
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	50.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	1.162E+5
Heat Transferred (BTU/hr)	8.6E+6
LMTD	91.9
Effective Area (ft²)	471.2

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,032.5
Tube-Side hi (BTU/hr·ft²·°F)	719.6
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9756
U Overall (BTU/hr·ft²·°F)	203.6

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	2.38
Reynold's Number	8.251E+04	1.520E+04
Prandtl Number	2.14	5.33
Bulk Visc (lbm/ft·hr)	0.82	1.91
Skin Visc (lbm/ft·hr)	0.88	1.37
Density (lbm/ft³)	60.53	62.15
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.36

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	173.9
Tav Shell (°F)	181.9
Shell Skin Temp (°F)	172.4
Tube Temp In (°F)	50.0
Tube Temp Out (°F)	124.1
Tav Tube (°F)	87.0
Tube Skin Temp (°F)	117.9

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

09:11:37 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 60°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data	
Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data	
Tube Flow (gpm)	269.1
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	60.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	1.346E+5
Heat Transferred (BTU/hr)	8.6E+6
LMTD	87.8
Effective Area (ft²)	471.2

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,032.7
Tube-Side hi (BTU/hr·ft²·°F)	828.7
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9770
U Overall (BTU/hr·ft²·°F)	212.7

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	2.76
Reynold's Number	8.251E+04	1.865E+04
Prandtl Number	2.14	5.00
Bulk Visc (lbm/ft·hr)	0.82	1.80
Skin Visc (lbm/ft·hr)	0.88	1.37
Density (lbm/ft³)	60.53	62.09
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.36

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	173.9
Tav Shell (°F)	181.9
Shell Skin Temp (°F)	172.5
Tube Temp In (°F)	60.0
Tube Temp Out (°F)	123.9
Tav Tube (°F)	92.0
Tube Skin Temp (°F)	118.5

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

09:06:52 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 70°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data	
Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data	
Tube Flow (gpm)	321.0
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	70.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	1.606E+5
Heat Transferred (BTU/hr)	8.6E+6
LMTD	83.7
Effective Area (ft²)	471.2

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,032.8
Tube-Side hi (BTU/hr·ft²·°F)	975.6
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9790
U Overall (BTU/hr·ft²·°F)	222.6

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	3.30
Reynold's Number	8.251E+04	2.348E+04
Prandtl Number	2.14	4.71
Bulk Visc (lbm/ft·hr)	0.82	1.71
Skin Visc (lbm/ft·hr)	0.88	1.36
Density (lbm/ft³)	60.53	62.03
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.36

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	173.9
Tav Shell (°F)	181.9
Shell Skin Temp (°F)	172.6
Tube Temp In (°F)	70.0
Tube Temp Out (°F)	123.6
Tav Tube (°F)	96.8
Tube Skin Temp (°F)	119.2

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

09:03:56 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 80°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date
Shell Flow (gpm)
Shell Temp In (°F)
Shell Temp Out (°F)
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)

Extrapolation Data

Tube Flow (gpm)	399.3
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	80.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)
Tube Mass Flow (lbm/hr)

Heat Transferred (BTU/hr)
LMTD
Effective Area (ft²)

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

U Overall (BTU/hr·ft²·°F)
Shell-Side ho (BTU/hr·ft²·°F)
Tube-Side hi (BTU/hr·ft²·°F)
1/Wall Resis (BTU/hr·ft²·°F)
LMTD Correction Factor

Overall Fouling (hr·ft²·°F/BTU)

Shell Temp In (°F)
Shell Temp Out (°F)
Tav Shell (°F)
Shell Skin Temp (°F)
Tube Temp In (°F)
Tube Temp Out (°F)
Tav Tube (°F)
Tube Skin Temp (°F)

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	1.997E+5
Heat Transferred (BTU/hr)	8.6E+6
LMTD	79.6
Effective Area (ft²)	471.2

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	4.11
Reynold's Number	8.251E+04	3.075E+04
Prandtl Number	2.14	4.45
Bulk Visc (lbm/ft·hr)	0.82	1.62
Skin Visc (lbm/ft·hr)	0.88	1.35
Density (lbm/ft³)	60.53	61.97
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.36

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,033.0
Tube-Side hi (BTU/hr·ft²·°F)	1,186.3
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9814
U Overall (BTU/hr·ft²·°F)	233.5
Shell Temp In (°F)	190.0
Shell Temp Out (°F)	173.9
Tav Shell (°F)	181.9
Shell Skin Temp (°F)	172.7
Tube Temp In (°F)	80.0
Tube Temp Out (°F)	123.1
Tav Tube (°F)	101.5
Tube Skin Temp (°F)	119.8

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

09:00:52 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 90°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data	
Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data	
Tube Flow (gpm)	530.9
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	90.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	2.656E+5
Heat Transferred (BTU/hr)	8.6E+6
LMTD	75.4
Effective Area (ft²)	471.2

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,033.2
Tube-Side hi (BTU/hr·ft²·°F)	1,519.8
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9845
U Overall (BTU/hr·ft²·°F)	245.7

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	5.47
Reynold's Number	8.251E+04	4.293E+04
Prandtl Number	2.14	4.22
Bulk Visc (lbm/ft·hr)	0.82	1.54
Skin Visc (lbm/ft·hr)	0.88	1.34
Density (lbm/ft³)	60.53	61.91
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.37

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	173.9
Tav Shell (°F)	181.9
Shell Skin Temp (°F)	172.8
Tube Temp In (°F)	90.0
Tube Temp Out (°F)	122.4
Tav Tube (°F)	106.2
Tube Skin Temp (°F)	120.3

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

Proto-Power Calc: 97-195
Attachment: G
Rev: A Page 8 of 17

08:54:07 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 100°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data

Tube Flow (gpm)	795.3
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	100.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	3.978E+5
Heat Transferred (BTU/hr)	8.6E+6
LMTD	71.1
Effective Area (ft²)	471.2

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	8.20
Reynold's Number	8.251E+04	6.738E+04
Prandtl Number	2.14	4.01
Bulk Visc (lbm/ft·hr)	0.82	1.47
Skin Visc (lbm/ft·hr)	0.88	1.34
Density (lbm/ft³)	60.53	61.85
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.37

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,033.3
Tube-Side hi (BTU/hr·ft²·°F)	2,140.0
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9885
U Overall (BTU/hr·ft²·°F)	259.7
Shell Temp In (°F)	190.0
Shell Temp Out (°F)	173.9
Tav Shell (°F)	181.9
Shell Skin Temp (°F)	172.9
Tube Temp In (°F)	100.0
Tube Temp Out (°F)	121.6
Tav Tube (°F)	110.8
Tube Skin Temp (°F)	120.8

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

11:02:12 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 35°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data	
Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data	
Tube Flow (gpm)	161.1
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	35.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	8.059E+4
Heat Transferred (BTU/hr)	7.8E+6
LMTD	93.3
Effective Area (ft²)	471.2

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,037.1
Tube-Side hi (BTU/hr·ft²·°F)	531.4
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9713
U Overall (BTU/hr·ft²·°F)	182.6

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	1.65
Reynold's Number	8.292E+04	1.010E+04
Prandtl Number	2.13	5.59
Bulk Visc (lbm/ft·hr)	0.82	1.99
Skin Visc (lbm/ft·hr)	0.87	1.31
Density (lbm/ft³)	60.52	62.18
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.36

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	175.4
Tav Shell (°F)	182.7
Shell Skin Temp (°F)	173.8
Tube Temp In (°F)	35.0
Tube Temp Out (°F)	131.8
Tav Tube (°F)	83.4
Tube Skin Temp (°F)	122.7

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 40°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data	
Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data	
Tube Flow (gpm)	169.8
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	40.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	8.492E+4
Heat Transferred (BTU/hr)	7.8E+6
LMTD	91.4
Effective Area (ft²)	471.2

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,037.2
Tube-Side hi (BTU/hr·ft²·°F)	561.0
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9716
U Overall (BTU/hr·ft²·°F)	186.5

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	1.74
Reynold's Number	8.292E+04	1.097E+04
Prandtl Number	2.13	5.40
Bulk Visc (lbm/ft·hr)	0.82	1.93
Skin Visc (lbm/ft·hr)	0.87	1.31
Density (lbm/ft³)	60.52	62.16
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.36

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	175.4
Tav Shell (°F)	182.7
Shell Skin Temp (°F)	173.8
Tube Temp In (°F)	40.0
Tube Temp Out (°F)	131.9
Tav Tube (°F)	86.0
Tube Skin Temp (°F)	122.9

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

10:40:50 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 50°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date
Shell Flow (gpm)
Shell Temp In (°F)
Shell Temp Out (°F)
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)

Extrapolation Data

Tube Flow (gpm)	190.5
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	50.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)
Tube Mass Flow (lbm/hr)

Heat Transferred (BTU/hr)
LMTD
Effective Area (ft²)

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

U Overall (BTU/hr·ft²·°F)
Shell-Side ho (BTU/hr·ft²·°F)
Tube-Side hi (BTU/hr·ft²·°F)
1/Wall Resis (BTU/hr·ft²·°F)
LMTD Correction Factor

Overall Fouling (hr·ft²·°F/BTU)

Shell Temp In (°F)
Shell Temp Out (°F)
Tav Shell (°F)
Shell Skin Temp (°F)
Tube Temp In (°F)
Tube Temp Out (°F)
Tav Tube (°F)
Tube Skin Temp (°F)

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	9.527E+4
Heat Transferred (BTU/hr)	7.8E+6
LMTD	87.5
Effective Area (ft²)	471.2

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	1.96
Reynold's Number	8.292E+04	1.305E+04
Prandtl Number	2.13	5.06
Bulk Visc (lbm/ft·hr)	0.82	1.82
Skin Visc (lbm/ft·hr)	0.87	1.30
Density (lbm/ft³)	60.52	62.10
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.36

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,037.4
Tube-Side hi (BTU/hr·ft²·°F)	629.9
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9726
U Overall (BTU/hr·ft²·°F)	194.6

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	175.4
Tav Shell (°F)	182.7
Shell Skin Temp (°F)	173.9
Tube Temp In (°F)	50.0
Tube Temp Out (°F)	131.9
Tav Tube (°F)	91.0
Tube Skin Temp (°F)	123.6

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

10:24:06

PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)

06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 60°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data

Tube Flow (gpm)	217.5
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	60.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	1.088E+5
Heat Transferred (BTU/hr)	7.8E+6
LMTD	83.6
Effective Area (ft²)	471.2

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,037.6
Tube-Side hi (BTU/hr·ft²·°F)	716.3
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9739
U Overall (BTU/hr·ft²·°F)	203.3

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	2.24
Reynold's Number	8.292E+04	1.575E+04
Prandtl Number	2.13	4.76
Bulk Visc (lbm/ft·hr)	0.82	1.72
Skin Visc (lbm/ft·hr)	0.87	1.29
Density (lbm/ft³)	60.52	62.05
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.36

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	175.4
Tav Shell (°F)	182.7
Shell Skin Temp (°F)	174.0
Tube Temp In (°F)	60.0
Tube Temp Out (°F)	131.8
Tav Tube (°F)	95.9
Tube Skin Temp (°F)	124.2

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

10:16:36 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 70°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data

Tube Flow (gpm)	254.2
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	70.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	1.272E+5
Heat Transferred (BTU/hr)	7.8E+6
LMTD	79.7
Effective Area (ft²)	471.2

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,037.8
Tube-Side hi (BTU/hr·ft²·°F)	829.2
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9757
U Overall (BTU/hr·ft²·°F)	212.8

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	2.62
Reynold's Number	8.292E+04	1.940E+04
Prandtl Number	2.13	4.50
Bulk Visc (lbm/ft·hr)	0.82	1.63
Skin Visc (lbm/ft·hr)	0.87	1.29
Density (lbm/ft³)	60.52	61.99
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.36

Shell Temp In (°F)	190.0
Shell Temp Out (°F)	175.4
Tav Shell (°F)	182.7
Shell Skin Temp (°F)	174.1
Tube Temp In (°F)	70.0
Tube Temp Out (°F)	131.4
Tav Tube (°F)	100.7
Tube Skin Temp (°F)	124.9

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

10:12:25 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 80°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date
Shell Flow (gpm)
Shell Temp In (°F)
Shell Temp Out (°F)
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)

Extrapolation Data

Tube Flow (gpm)	307.0
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	80.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)
Tube Mass Flow (lbm/hr)

Heat Transferred (BTU/hr)
LMTD
Effective Area (ft²)

U Overall (BTU/hr·ft²·°F)
Shell-Side ho (BTU/hr·ft²·°F)
Tube-Side hi (BTU/hr·ft²·°F)
1/Wall Resis (BTU/hr·ft²·°F)
LMTD Correction Factor

Overall Fouling (hr·ft²·°F/BTU)

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)
Shell Temp Out (°F)
Tav Shell (°F)
Shell Skin Temp (°F)
Tube Temp In (°F)
Tube Temp Out (°F)
Tav Tube (°F)
Tube Skin Temp (°F)

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	1.536E+5
Heat Transferred (BTU/hr)	7.8E+6
LMTD	75.8
Effective Area (ft²)	471.2

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	3.16
Reynold's Number	8.292E+04	2.462E+04
Prandtl Number	2.13	4.26
Bulk Visc (lbm/ft·hr)	0.82	1.56
Skin Visc (lbm/ft·hr)	0.87	1.28
Density (lbm/ft³)	60.52	61.92
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.37

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,038.0
Tube-Side hi (BTU/hr·ft²·°F)	984.2
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9779
U Overall (BTU/hr·ft²·°F)	223.2
Shell Temp In (°F)	190.0
Shell Temp Out (°F)	175.4
Tav Shell (°F)	182.7
Shell Skin Temp (°F)	174.2
Tube Temp In (°F)	80.0
Tube Temp Out (°F)	130.8
Tav Tube (°F)	105.4
Tube Skin Temp (°F)	125.6

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

10:08:33 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 90°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Shell Flow (gpm)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	

Extrapolation Data

Tube Flow (gpm)	389.3
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	90.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)	
Tube Mass Flow (lbm/hr)	
Heat Transferred (BTU/hr)	
LMTD	
Effective Area (ft²)	

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

U Overall (BTU/hr·ft²·°F)	
Shell-Side ho (BTU/hr·ft²·°F)	
Tube-Side hi (BTU/hr·ft²·°F)	
1/Wall Resis (BTU/hr·ft²·°F)	
LMTD Correction Factor	
Overall Fouling (hr·ft²·°F/BTU)	
Shell Temp In (°F)	
Shell Temp Out (°F)	
Tav Shell (°F)	
Shell Skin Temp (°F)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Tav Tube (°F)	
Tube Skin Temp (°F)	

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	1.947E+5
Heat Transferred (BTU/hr)	7.8E+6
LMTD	71.9
Effective Area (ft²)	471.2

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	4.01
Reynold's Number	8.292E+04	3.273E+04
Prandtl Number	2.13	4.04
Bulk Visc (lbm/ft·hr)	0.82	1.48
Skin Visc (lbm/ft·hr)	0.87	1.27
Density (lbm/ft³)	60.52	61.86
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.37

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,038.2
Tube-Side hi (BTU/hr·ft²·°F)	1,213.3
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9808
U Overall (BTU/hr·ft²·°F)	234.8
Shell Temp In (°F)	190.0
Shell Temp Out (°F)	175.4
Tav Shell (°F)	182.7
Shell Skin Temp (°F)	174.3
Tube Temp In (°F)	90.0
Tube Temp Out (°F)	130.1
Tav Tube (°F)	110.1
Tube Skin Temp (°F)	126.2

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

10:03:05 **PROTO-HX 3.02 by Proto-Power Corporation (SN#PHX-0000)** 06/29/98

Commonwealth Edison

Calculation Report for DG01A - DG Jacket Water Cooler

CSCS = 100°F

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date
Shell Flow (gpm)
Shell Temp In (°F)
Shell Temp Out (°F)
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)

Extrapolation Data

Tube Flow (gpm)	534.5
Shell Flow (gpm)	1,064.5
Tube Inlet Temp (°F)	100.0
Shell Inlet Temp (°F)	190.0

Fouling Calculation Results

Shell Mass Flow (lbm/hr)
Tube Mass Flow (lbm/hr)

Heat Transferred (BTU/hr)
LMTD
Effective Area (ft²)

U Overall (BTU/hr·ft²·°F)
Shell-Side ho (BTU/hr·ft²·°F)
Tube-Side hi (BTU/hr·ft²·°F)
1/Wall Resis (BTU/hr·ft²·°F)
LMTD Correction Factor

Overall Fouling (hr·ft²·°F/BTU)

Property	Shell-Side	Tube-Side
Velocity (ft/s)		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Shell Temp In (°F)
Shell Temp Out (°F)
Tav Shell (°F)
Shell Skin Temp (°F)
Tube Temp In (°F)
Tube Temp Out (°F)
Tav Tube (°F)
Tube Skin Temp (°F)

Extrapolation Calculation Results

Shell Mass Flow (lbm/hr)	5.325E+5
Tube Mass Flow (lbm/hr)	2.674E+5
Heat Transferred (BTU/hr)	7.8E+6
LMTD	67.8
Effective Area (ft²)	471.2

Property	Shell-Side	Tube-Side
Velocity (ft/s)	4.99	5.52
Reynold's Number	8.292E+04	4.701E+04
Prandtl Number	2.13	3.85
Bulk Visc (lbm/ft·hr)	0.82	1.42
Skin Visc (lbm/ft·hr)	0.87	1.27
Density (lbm/ft³)	60.52	61.79
Cp (BTU/lbm·°F)	1.00	1.00
K (BTU/hr·ft·°F)	0.39	0.37

Overall Fouling (hr·ft²·°F/BTU)	0.002782
Shell-Side ho (BTU/hr·ft²·°F)	2,038.4
Tube-Side hi (BTU/hr·ft²·°F)	1,592.6
1/Wall Resis (BTU/hr·ft²·°F)	25,594.8
LMTD Correction Factor	0.9844
U Overall (BTU/hr·ft²·°F)	247.9
Shell Temp In (°F)	190.0
Shell Temp Out (°F)	175.4
Tav Shell (°F)	182.7
Shell Skin Temp (°F)	174.4
Tube Temp In (°F)	100.0
Tube Temp Out (°F)	129.2
Tav Tube (°F)	114.6
Tube Skin Temp (°F)	126.8

** Reynolds Number Outside Range of Equation Applicability
!! With Minimum Fouling The Test Heat Load Could Not Be Achie

Attachment H to
Proto-Power Calculation
97-195
Revision A

PROTO-HX™ Version 3.02 MODEL

LASALLE STATION STANDBY DIESEL GENERATOR HEAT EXCHANGER.

FILE NAME:	**DG01A.PHX**
DATE LAST MODIFIED:	**6/29/98**
TIME LAST MODIFIED:	**1:50:34 PM**
FILE SIZE:	**640 KB**

ATTACHMENT 2
Design Analysis Minor Revision Cover Sheet

Page 1

Design Analysis (Minor Revision) | **Last Page No.** [6] Attachment A, A9

Analysis No.: [1] 97-199 **Revision:** [2] B03

Title: [3] VY Cooler Thermal Performance Model – 1(2)VY03A

EC/ECR No.: [4] 388666 **Revision:** [5] 000

Station(s): [7] LaSalle

Unit No.: [8] 01 & 02

Safety/QA Class: [9] SR

System Code(s): [10] VY

Is this Design Analysis Safeguards Information? [11] Yes ☐ No ☒ If yes, see SY-AA-101-106

Does this Design Analysis contain Unverified Assumptions? [12] Yes ☐ No ☒ If yes, ATI/AR#: N/A

This Design Analysis SUPERCEDES: [13] **N/A** **in its entirety.**

Description of Changes (list affected pages): [14]
This revision evaluates a maximum cooling water inlet temperature of 107 °F. The previous temperature that was evaluated was 104 °F. Affected pages are Pages 1 - 2 and Attachment A, Pages A1-A9.

Disposition of Changes: [15]
See attached pages. The changes made are acceptable.

Preparer: [16] Sean Tanton (Print Name) Sean Tanton (Sign Name) 4/27/12 (Date)

Method of Review: [17] **Detailed Review** ☒ **Alternate Calculations** ☐ **Testing** ☐

Reviewer: [18] Steve Chan (Print Name) Va Chan (Sign Name) 5/16/12 (Date)

Review Notes: [19] Independent review ☒ Peer review ☐

(For External Analyses Only)

External Approver: [20] NA (Print Name) (Sign Name) (Date)

Exelon Reviewer [21] NA (Print Name) (Sign Name) (Date)

Exelon Approver: [22] DAN SCHMIT (Print Name) DA Schmit (Sign Name) 5/17/12 (Date)

Purpose:
The purpose of this revision is to verify that the 1(2)VY03A cooler can remove the design heat load of 722,217 BTU/hr with a revised maximum cooling water temperature of 107 °F.

Assumptions:
There are no assumptions for this revision.

Inputs:
- Cooling water temperature = 107 °F (Reference 2)
- Air temperature = 148 °F (Reference 1)
- Water flow rate = 72.5 gpm (Reference 1)
- Air Flow rate = 23,760 cfm (Reference 1)
- Fouling factor = 0.02650655 hr·ft^2·°F/BTU (design fouling factor) (Reference 1)
- 1 tube plugged (5% tube plugging) (Reference 1)

References:
1. Design analysis 97-199, Rev. B, up to and including Revs B00 through B02
2. EC 388666, Rev. 000

Identification of Computer Programs:
The computer program used in this analysis is Proto HX version 4.01. This program has been validated per DTSQA tracking number EX0000103.

Method of Analysis / Numeric Analysis:
The existing heat exchanger model will be revised by changing the input of the "Tube Inlet Temp" from 104 °F to 107 °F. Because the fan for the 1(2)VY03A cooler is at the exit of the cooler, the inlet air flow for the front cooler is iterated until the flow rate at the exit of the last row of the cooler is approximately 23,760 cfm. The iteration process is detailed in section 6.7 of revision B. The air flow values can be found on pages A9 for the case that was considered.

Results / Conclusions:
The 1(2)VY03A coolers can remove the design heat load of 722,217 BTU/hr with the following conditions:
- 107 °F cooling water temperature
- 148 °F air temperature
- design fouling factor of 0.02650655 hr·ft^2·°F/BTU
- 1 tube plugged
- air flow rate of 23,760 cfm
- water flow rate of 72.5 gpm

The total heat removed at these conditions is 757,712 BTU/hr, which provides 4.9% thermal margin over the design heat load. This thermal margin is enough to account for the 4.5% model uncertainty shown in Attachment J and is acceptable. Note that a maximum fouling factor was not calculated as was done in previous revisions because it is not practical to set up test conditions that would allow accurate measurement of the fouling factor for these heat exchangers. The bounding fouling factor is the design fouling factor of 0.02650655 hr·ft^2·°F/BTU. This case is shown in Attachment A.

Attachments:
A. Data Report for 1(2)VY03A (9 pgs)

ComEd -- LaSalle

Data Report for 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 - 148 °F air side, 23,760 cfm, 107 °F water side, 72.5 gpm, Design FF, 1 tube plugged

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Flow	31,066.00 acfm	180.00 gpm
Mass Flow	0.00 lbm/hr	0.00 lbm/hr
Dry Bulb (Inlet Temperature)	150.00 °F	105.00 °F
Inlet Wet Bulb Temperature	92.00 °F	
Inlet Relative Humidity	0.00 %	
Dry Bulb (Outlet Temperature)	108.80 °F	117.70 °F
Outlet Wet Bulb Temperature	84.00 °F	
Outlet Relative Humidity	0.00 %	

Tube Fluid Name	Fresh Water
Tube-Side Fouling	0.001500
Air-Side Fouling	0.000000
Design Q (BTU/hr)	1,108,000
Atmospheric Pressure (psia)	14.315
Design Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Coil Flow Direction	Counter Flow
Fin Type	Circular Fins
Configuration (for Air-Side h)	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	23.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Conductivity (BTU/hr·ft·°F)	225.00

ComEd -- LaSalle

Calculation Report for 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 - 148 °F air side, 23,760 cfm, 107 °F water side, 72.5 gpm, Design FF, 1 tube plugged

Calculation Specifications

Constant Inlet Temperature Method Was Used

Extrapolation Was to User Specified Conditions

Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure (psia)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	25,109.00
Tube Inlet Temp (°F)	107.00
Air Inlet Temp (°F)	148.00
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure (psia)	14.315

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

ComEd -- LaSalle

Calculation Report for 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 - 148 °F air side, 23,760 cfm, 107 °F water side, 72.5 gpm, Design FF, 1 tube plugged

Extrapolation Calculation Summary

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	92,786.23	35,999.06
Inlet Temperature (°F)	148.00	107.00
Outlet Temperature (°F)	115.36	128.06
Inlet Specific Humidity		
Outlet Specific Humidity		

Tube-Side hi (BTU/hr·ft²·°F)	0.00
j Factor	0.0000
Air-Side ho (BTU/hr·ft²·°F)	0.00
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	10,093.49
LMTD	0.00
Total Heat Transferred (BTU/hr)	757,712
Surface Effectiveness (Eta)	0.0000
Sensible Heat Transferred (BTU/hr)	757,712
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	92,786.23	35,999.06
Inlet Temperature (°F)	148.00	125.01
Outlet Temperature (°F)	143.27	128.06
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	145.63	126.5327
Skin Temperature (°F)	131.69	128.7549
Velocity ***	3,921.86	2.3294
Reynold's Number	874**	17,899
Prandtl Number	0.7253	3.4023
Bulk Visc (lbm/ft·hr)	0.0491	1.2676
Skin Visc (lbm/ft·hr)	0.0000	1.2425
Density (lbm/ft³)	0.0621	61.6077
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0163	0.3722
Relative Humidity In (%)	12.76	
Relative Humidity Out (%)	14.37	

Tube-Side hi (BTU/hr·ft²·°F)	871.38
j Factor	0.0073
Air-Side ho (BTU/hr·ft²·°F)	8.50
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.74
Effective Area (ft²)	1,009.35
LMTD	18.97
Total Heat Transferred (BTU/hr)	109,834
Surface Effectiveness (Eta)	0.9250
Sensible Heat Transferred (BTU/hr)	109,834
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	92,786.23	35,999.06
Inlet Temperature (°F)	143.27	122.22
Outlet Temperature (°F)	138.95	125.01
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	141.11	123.6110
Skin Temperature (°F)	128.35	125.6691
Velocity ***	3,921.86	2.3276
Reynold's Number	879**	17,428
Prandtl Number	0.7257	3.5030
Bulk Visc (lbm/ft·hr)	0.0488	1.3019
Skin Visc (lbm/ft·hr)	0.0000	1.2776
Density (lbm/ft³)	0.0625	61.6549
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3712
Relative Humidity In (%)	14.37	
Relative Humidity Out (%)	16.05	

Tube-Side hi (BTU/hr·ft²·°F)	858.99
j Factor	0.0073
Air-Side ho (BTU/hr·ft²·°F)	8.48
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.72
Effective Area (ft²)	1,009.35
LMTD	17.38
Total Heat Transferred (BTU/hr)	100,285
Surface Effectiveness (Eta)	0.9252
Sensible Heat Transferred (BTU/hr)	100,285
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	92,786.23	35,999.06
Inlet Temperature (°F)	138.95	119.67
Outlet Temperature (°F)	135.00	122.22
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	136.97	120.9425
Skin Temperature (°F)	125.30	122.8478
Velocity ***	3,921.86	2.3260
Reynold's Number	884**	17,001
Prandtl Number	0.7261	3.5994
Bulk Visc (lbm/ft·hr)	0.0486	1.3346
Skin Visc (lbm/ft·hr)	0.0000	1.3111
Density (lbm/ft³)	0.0629	61.6970
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3703
Relative Humidity In (%)	16.05	
Relative Humidity Out (%)	17.79	

Tube-Side hi (BTU/hr·ft²·°F)	847.63
j Factor	0.0073
Air-Side ho (BTU/hr·ft²·°F)	8.46
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.70
Effective Area (ft²)	1,009.35
LMTD	15.92
Total Heat Transferred (BTU/hr)	91,613
Surface Effectiveness (Eta)	0.9253
Sensible Heat Transferred (BTU/hr)	91,613
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	92,786.23	35,999.06	Tube-Side hi (BTU/hr·ft^2·°F)	837.20
Inlet Temperature (°F)	135.00	117.34	j Factor	0.0072
Outlet Temperature (°F)	131.39	119.67	Air-Side ho (BTU/hr·ft^2·°F)	8.44
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
Average Temp (°F)	133.20	118.5042		
Skin Temperature (°F)	122.51	120.2672	U Overall (BTU/hr·ft^2·°F)	5.68
Velocity ***	3,921.86	2.3246	Effective Area (ft^2)	1,009.35
Reynold's Number	888**	16,614	LMTD	14.59
Prandtl Number	0.7264	3.6913	Total Heat Transferred (BTU/hr)	83,730
Bulk Visc (lbm/ft·hr)	0.0483	1.3656		
Skin Visc (lbm/ft·hr)	0.0000	1.3431	Surface Effectiveness (Eta)	0.9254
Density (lbm/ft^3)	0.0633	61.7347	Sensible Heat Transferred (BTU/hr)	83,730
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0160	0.3695	Heat to Condensate (BTU/hr)	
Relative Humidity In (%)	17.79			
Relative Humidity Out (%)	19.56			

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	92,786.23	35,999.06	Tube-Side hi (BTU/hr·ft^2·°F)	827.64
Inlet Temperature (°F)	131.39	115.21	j Factor	0.0072
Outlet Temperature (°F)	128.09	117.34	Air-Side ho (BTU/hr·ft^2·°F)	8.43
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
Average Temp (°F)	129.74	116.2751		
Skin Temperature (°F)	119.95	117.9057	U Overall (BTU/hr·ft^2·°F)	5.67
Velocity ***	3,921.86	2.3234	Effective Area (ft^2)	1,009.35
Reynold's Number	892**	16,263	LMTD	13.38
Prandtl Number	0.7267	3.7787	Total Heat Transferred (BTU/hr)	76,559
Bulk Visc (lbm/ft·hr)	0.0481	1.3951		
Skin Visc (lbm/ft·hr)	0.0000	1.3735	Surface Effectiveness (Eta)	0.9256
Density (lbm/ft^3)	0.0637	61.7685	Sensible Heat Transferred (BTU/hr)	76,559
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0159	0.3688	Heat to Condensate (BTU/hr)	
Relative Humidity In (%)	19.56			
Relative Humidity Out (%)	21.37			

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	**Tube-Side**		
Mass Flow (lbm/hr)	92,786.23	35,999.06	Tube-Side hi (BTU/hr·ft^2·°F)	818.86
Inlet Temperature (°F)	128.09	113.26	j Factor	0.0072
Outlet Temperature (°F)	125.08	115.21	Air-Side ho (BTU/hr·ft^2·°F)	8.41
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
Average Temp (°F)	126.59	114.2366		
Skin Temperature (°F)	117.62	115.7441	U Overall (BTU/hr·ft^2·°F)	5.66
Velocity ***	3,921.86	2.3222	Effective Area (ft^2)	1,009.35
Reynold's Number	896**	15,944	LMTD	12.27
Prandtl Number	0.7269	3.8617	Total Heat Transferred (BTU/hr)	70,031
Bulk Visc (lbm/ft·hr)	0.0479	1.4230		
Skin Visc (lbm/ft·hr)	0.0000	1.4023	Surface Effectiveness (Eta)	0.9257
Density (lbm/ft^3)	0.0640	61.7988	Sensible Heat Transferred (BTU/hr)	70,031
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0158	0.3681	Heat to Condensate (BTU/hr)	
Relative Humidity In (%)	21.37			
Relative Humidity Out (%)	23.18			

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 7(Dry)

	Air-Side	**Tube-Side**		
Mass Flow (lbm/hr)	92,786.23	35,999.06	Tube-Side hi (BTU/hr·ft^2·°F)	810.81
Inlet Temperature (°F)	125.08	111.48	j Factor	0.0072
Outlet Temperature (°F)	122.32	113.26	Air-Side ho (BTU/hr·ft^2·°F)	8.40
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
Average Temp (°F)	123.70	112.3716		
Skin Temperature (°F)	115.48	113.7647	U Overall (BTU/hr·ft^2·°F)	5.64
Velocity ***	3,921.86	2.3212	Effective Area (ft^2)	1,009.35
Reynold's Number	899**	15,655	LMTD	11.25
Prandtl Number	0.7272	3.9402	Total Heat Transferred (BTU/hr)	64,083
Bulk Visc (lbm/ft·hr)	0.0477	1.4493		
Skin Visc (lbm/ft·hr)	0.0000	1.4296	Surface Effectiveness (Eta)	0.9258
Density (lbm/ft^3)	0.0643	61.8261	Sensible Heat Transferred (BTU/hr)	64,083
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0158	0.3674	Heat to Condensate (BTU/hr)	
Relative Humidity In (%)	23.18			
Relative Humidity Out (%)	25.01			

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	92,786.23	35,999.06
Inlet Temperature (°F)	122.32	109.85
Outlet Temperature (°F)	119.79	111.48
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	121.05	110.6647
Skin Temperature (°F)	113.52	111.9516
Velocity ***	3,921.86	2.3203
Reynold's Number	902**	15,391
Prandtl Number	0.7273	4.0144
Bulk Visc (lbm/ft·hr)	0.0476	1.4742
Skin Visc (lbm/ft·hr)	0.0000	1.4554
Density (lbm/ft^3)	0.0646	61.8506
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3668
Relative Humidity In (%)	25.01	
Relative Humidity Out (%)	26.82	

Tube-Side hi (BTU/hr·ft^2·°F)	803.42
j Factor	0.0072
Air-Side ho (BTU/hr·ft^2·°F)	8.39
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	5.63
Effective Area (ft^2)	1,009.35
LMTD	10.32
Total Heat Transferred (BTU/hr)	58,661
Surface Effectiveness (Eta)	0.9259
Sensible Heat Transferred (BTU/hr)	58,661
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	92,786.23	35,999.06
Inlet Temperature (°F)	119.79	108.36
Outlet Temperature (°F)	117.48	109.85
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	118.63	109.1020
Skin Temperature (°F)	111.73	110.2904
Velocity ***	3,921.86	2.3194
Reynold's Number	905**	15,151
Prandtl Number	0.7275	4.0844
Bulk Visc (lbm/ft·hr)	0.0474	1.4975
Skin Visc (lbm/ft·hr)	0.0000	1.4797
Density (lbm/ft^3)	0.0648	61.8727
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3662
Relative Humidity In (%)	26.82	
Relative Humidity Out (%)	28.61	

Tube-Side hi (BTU/hr·ft^2·°F)	796.64
j Factor	0.0072
Air-Side ho (BTU/hr·ft^2·°F)	8.38
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	5.62
Effective Area (ft^2)	1,009.35
LMTD	9.47
Total Heat Transferred (BTU/hr)	53,715
Surface Effectiveness (Eta)	0.9260
Sensible Heat Transferred (BTU/hr)	53,715
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

ComEd -- LaSalle

Calculation Report for 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 - 148 °F air side, 23,760 cfm, 107 °F water side, 72.5 gpm, Design FF, 1 tube plugged

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	92,786.23	35,999.06
Inlet Temperature (°F)	117.48	106.99
Outlet Temperature (°F)	115.36	108.36
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	116.42	107.6708
Skin Temperature (°F)	110.08	108.7679
Velocity ***	3,921.86	2.3187
Reynold's Number	908**	14,933
Prandtl Number	0.7276	4.1502
Bulk Visc (lbm/ft·hr)	0.0473	1.5194
Skin Visc (lbm/ft·hr)	0.0000	1.5026
Density (lbm/ft³)	0.0651	61.8926
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0156	0.3657
Relative Humidity In (%)	28.61	
Relative Humidity Out (%)	30.37	

Tube-Side hi (BTU/hr·ft²·°F)	790.41
j Factor	0.0072
Air-Side ho (BTU/hr·ft²·°F)	8.37
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.61
Effective Area (ft²)	1,009.35
LMTD	8.69
Total Heat Transferred (BTU/hr)	49,200
Surface Effectiveness (Eta)	0.9260
Sensible Heat Transferred (BTU/hr)	49,200
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Formulas from Section 6.7 for iteration process to determine inlet airflow for extrapolation conditions						
Total P:	P =			14.315	psia	
Dry Bulb T OUT:	T1 =			115.36	F	
Specific Hum.:	W =			0.0203		
H2O Vap. P:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =			0.452444	psia	
			Rv =	85.778	(ft-lbf)/(lbm-R)	
			Ra =	53.352	(ft-lbf)/(lbm-R)	
Dry Air P:	Pa = P - Pv =			13.86256	psia	
Dry Air rho OUT:	rho.out = (144/Ra)*(Pa/(459.67+T1)) =			0.065068	lbm/ft^3	
Dry Air rho IN:	rho.in = (144/Ra)*(Pa/(459.67+T2)) =			0.061573	lbm/ft^3	
Dry Bulb T IN:	T2 =			148	F	
Outlet Air Flow:	V =			23760	cfm	
cfm.in	cfm.in = V*(rho.out/rho.in) =			25108.67	acfm	

ATTACHMENT 2
Design Analysis Minor Revision Cover Sheet

Design Analysis (Minor Revision)
Last Page No. [6] Attachment A page 7
Analysis No.: [1] 97-199 **Revision:** [2] B02
Title: [3] VY Cooler Thermal Performance Model – 1(2)VY03A
EC/ECR No.: [4] EC 368604 **Revision:** [5] 0

Station(s): [7] LaSalle
Unit No.: [8] 00
Safety/QA Class: [9] Safety Related
System Code(s): [10] VY

Is this Design Analysis Safeguards Information? [11] **Yes** ☐ **No** ☒ If yes, see SY-AA-101-106
Does this Design Analysis contain Unverified Assumptions? [12] **Yes** ☐ **No** ☒ If yes, ATI/AR#:
This Design Analysis SUPERCEDES: [13] N/A **in its entirety.**

Description of Changes (list affected pages): [14]

The following pages from ~~Rev. A of~~ 1/13/08 this calculation are affected by this minor revision: 2, 16, 22, 23 and 24 as well as Attachment A pages 2, 3, 4, 6 and 7. This minor revision incorporates the changes that were identified in IR 641522 as a result of the Key Calculation review effort. Page 2a was added as part of this minor rev. 1/10/08

The following changes were made:

1. Ref. 4 UFSAR Table 3.11-8 was replaced with Calculation L-002511.
2. References 5 and 6 were revised to indicate that they are uncontrolled and that the current UFSAR should be referenced to find current values. Subsequent revisions to calculation 97-199 have incorporated these changes to the UFSAR.
3. The references were corrected/revised as necessary to make them current.

Disposition of Changes: [15]

These changes are enhancements suggested as a result of a Key Calculation review. None of these changes adversely affect the ability of the 1(2)VY03A room coolers to perform their design function.

See Attached Pages for details

Preparer: [16] Debbie Henley (Print Name) Debbie Henley (Sign Name) 12/12/07 (Date)

Method of Review: [17] **Detailed Review** ☒ **Alternate Calculations** ☐ **Testing** ☐
Reviewer: [18] ERIC SHIAU (Print Name) (Sign Name) 12/13/07 (Date)
Review Notes: [19] Independent review ☒ Peer review ☐

(For External Analyses Only)
External Approver: [20] (Print Name) (Sign Name) (Date)
Exelon Reviewer [21] (Print Name) (Sign Name) (Date)
Exelon Approver: [22] W. Hilton (Print Name) (Sign Name) 12-13-07 (Date)

B02

PROTO-POWER CORPORATION GROTON, CONNECTICUT	CALC NO. 97-199	REV ~~A~~	PAGE 2 OF 24
	ORIGINATOR L. Philpot		DATE 7/7/98
	VERIFIED BY M. Aboye		JOB NO. 31-003
CLIENT Commonwealth Edison	PROJECT LaSalle Station GL 89-13 Heat Exchanger Testing		
TITLE VY Cooler Thermal Performance Model -- 1(2)VY03A			

B

3. DESIGN INPUTS

The thermal performance model is developed using PROTO-HX™, Version 3.01. PROTO-HX™ was developed and validated in accordance with Proto-Power's Nuclear Software Quality Assurance Program (SQAP). This program meets the requirements of 10CFR50 Appendix B, 10CFR21, and ANSI NQA-1, and was developed in accordance with the guidelines and standards contained in ANSI/IEEE Standard 730/1984 and ANSI NQA-2b-1991. PROTO-HX™ Version 3.01 was verified and approved for use as documented in Reference (1).

The design inputs for this calculation consist of the heat exchanger design basis performance requirements (Table1), performance specifications (Table 2) and construction details (Table 3) provided by the heat exchanger manufacturer data sheet (Attachment A) or other design documents as referenced. Construction details give the necessary information for model construction while performance specifications are used to benchmark the model.

VY cooler thermal performance in this calculation will be assessed only with respect to the nominal accident conditions (i.e., design basis LOCA) with no tubes plugged. Condensing modes of operation and tube plugging margins are not addressed.

Table 1: LaSalle Station Reference Conditions

Parameter	**Value**	**Reference***
Heat Rate -- 1(2)VY013A (BTU/hr)	722,217	2
Atmospheric Pressure (in-w.g.)	-0.4 (see Insert A next page)	4
Air-Side Inlet Temperature -- Dry Bulb (°F)	148	4
Fan Volumetric Flow Rate (cfm)	26,400	18,19
Tube-Side Flow Rate (gpm)	180**	5
Tube-Side Inlet Temperature (°F)	100 ***	6

*Selected references included as Attachment A

B02

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** While the model was created using a tube-side flow rate of 180gpm, the current value in the UFSAR is 72.5 gpm. This value is considered the minimum design flow and is evaluated in Section 7.3 and used in the current revision of the calc.

*** The UFSAR now allows an UHS maximum temperature of 104°F. The model was run in revision B00 with the higher inlet temperature.

B02

Insert A:

The basis for the -0.4 in.-w.g. atmospheric pressure in Table 1 in Rev. A0 was Ref. 4 UFSAR Table 3.11-8, provided in Attach. A. This value is used in determining the coil pressure value to be used in the Proto-HX thermal model. The –0.4 in. w.g. in this UFSAR table has subsequently been revised and is now 0 in. w.g. Nevertheless, as discussed on pgs. 9 and 12 of Calculation L-002511 Rev. 0, and as verified in Passport D071 panel for reactor building (RB) HVAC differential pressure controllers 1(2)PDC-VR007, the nominal value is still –0.4 in. w.g. Under abnormal conditions, the reactor building is maintained at least –0.25 in. w.g. by the Standby Gas Treatment System (VG), however there is a short period of time before VG starts during which RB pressure may approach 0 in. w.g. If both VG trains are operating, the pressure could reach a minimum of –0.69 in. w.g. until one train is secured. Recent surveillance test data (WO #727706 for Secondary Containment Leak Rate Test LTS-300-3) indicates with one train of VG in operation for at least 5 minutes, the refuel floor RB pressure averaged approx. –0.4 to -0.5 in. w.g.) In conclusion, the –0.4 in. w.g. pressure is still a reasonable value to use in conjunction with Proto-HX thermal performance evaluations. Slight variations, e.g. a difference of 0.4 – 0.25 = 0.15 in. w.g., equates to a pressure difference of 0.005 psig (see bottom of pg. 14/24 of Calculation.97-199 Rev. A).

For purposes of comparison, the Proto-Power Corp. (preparer/approver of Rev. A of the calculation) was contacted and the LaSalle Proto-HX model for 1(2)VY03A was run for two cases. Both cases used the same input parameters and extrapolation conditions, with the exception of the atmospheric pressure extrapolation condition. One case used an atmospheric pressure of 14.329 psig corresponding to 0.0 in. w.g. differential pressure in the cooler room, and one with 14.315 psig corresponding to the –0.4 in. w.g. differential room pressure. As expected based on discussions with the DEM HVAC engineer, these runs demonstrated that the calculated heat removal rate was essentially unchanged (calculated was actually slightly higher at the higher room pressure, however the difference was insignificant (0.1% higher)). Given the available heat transfer margin, small differences in ambient room pressure are therefore considered insignificant.

Per Revision B02, Reference 4 has been changed to calculation L-002511 Rev. 0A to provide the basis for the –0.4 in, w.g.

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PROTO-POWER CORPORATION **GROTON, CONNECTICUT**	CALC NO. 97-199	REV ~~A~~	PAGE 16 OF 24
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B0

The iteration process described above was completed twice for this model for a clean (f = 0.0) and service (f = design) condition with results as follows:

Clean:

$$(\text{cfm}_{\text{in}}) = (\text{cfm}_{\text{out}}) \times \frac{(\rho_{\text{out}})}{(\rho_{\text{in}})} = (26{,}400) \times \frac{(0.066345159)}{(0.061575103)} = 28{,}445 \text{ (Fan Temperature} = 104.31)$$

Service:

$$(\text{cfm}_{\text{in}}) = (\text{cfm}_{\text{out}}) \times \frac{(\rho_{\text{out}})}{(\rho_{\text{in}})} = (26{,}400) \times \frac{(0.066128241)}{(0.061575103)} = 28{,}352 \text{ (Fan Temperature} = 106.16)$$

Summary of PROTO-HX™ Inputs for Extrapolation to Reference Conditions

The Extrapolation conditions are defined as the vendor data sheet conditions without high energy line break modified for ultimate heat sink temperature and room limiting temperature per ~~the LaSalle Station UFSAR~~ Reference (4), and (6) B02

The required PROTO-HX™ inputs for these conditions are as follows:

Tube-Side Flow Rate	180 gpm *
Tube-Side Inlet Temperature	104 ~~100~~°F
Air-Side Flow Rate	(varies with temperature)
Air-Side Inlet Temperature -- Dry Bulb	148°F
Air-Side Inlet Humidity	12.76%
Atmospheric Pressure	14.315 psia

B02

6.8 Thermal Margin Assessment

The available thermal margin is defined as the difference between the available and the required heat removal rates at reference conditions. The maximum available heat removal rate is calculated using the benchmarked PROTO-HX™ model and the inlet conditions defined in Section 6.7 with zero fouling. By comparing the available heat removal rate calculated with zero fouling (q_{clean}) to the required heat removal rate, the maximum available margin is determined. A similar comparison is made between the required heat load to the available heat load at design fouling conditions (q_{service}).

* In the latest calc. revisions, a tube-side flow rate of 72.5 gpm is typically extrapolated to since section 7.3 determined this is the minimum design flow.

B0

B02

| B0

Table 12: Fouling Sensitivity Analysis – 1(2)VY03A at 72.5 gpm

Air-Side *f*	Tube-Side *f*	Required q	Available q	%Margin
0.0020	0.0000	722,217	1,002,563	38.82%
0.0020	0.0010	722,217	969,164	34.19%
0.0020	0.0020	722,217	938,124	29.90%
0.0020	0.0030	722,217	907,127	25.60%
0.0020	0.0040	722,217	879,956	21.84%

8. CONCLUSIONS

A model for the LaSalle County Station Units 1 & 2 SE Cubicle Area Coolers was developed using PROTO-HX™ Version 3.01. The model was benchmarked and validated using the performance specifications provided by the cooler vendor. The close correlation with vendor specified and model predicted thermal performance confirms that the models are to be considered acceptable for use in the GL 89-13 heat exchanger testing program and related performance analyses.

The available thermal margin for the coolers has been defined for the nameplate rated flow of 180 gpm and for a reduced flow rate of **72.5** gpm in support of service water system re-balancing efforts. Inclusion of a conservative assessment of the uncertainty in the analytical methods of PROTO-HX™ has provided high confidence in the thermal margins defined by the model for all cases.

The model database is saved under file name vy-03a.phx, with a file size of 1,277,952 bytes, and a file date and time of 7/6/98 at 6:21:52 pm. The saved database is set up to run the 72.5 gpm case with adjusted design fouling factors of 0.002 air-side and 0.002 tube-side. The database file is included as Attachment N.

9. REFERENCES

1. Heat Exchanger Thermal Performance Modeling Software Program PROTO-HX™ Version 3.01 Software Validation and Verification Report (SVVR) SQA No. SVVR-93948-02, Revision E, dated 11/5/97
2. LaSalle Calculation L-001077, Revision ~~2~~ 3A, RHR Pump A Cubicle Cooler Ventilation System | B02

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TITLE VY Cooler Thermal Performance Model -- 1(2)VY03A			

| B

3. Procedure LTS-200-19, Revision 4, performed on cooler 1VY03A on 6/12/98

4. ~~LaSalle Station Updated Final Safety Analysis Report, Table 3.11-8, Harsh Environment Zone H6 -- Bounding Environmental Conditions Inside the ECCS Cubicles (Attachment A)~~ LaSalle Calculation L-002511, Revision 0A, Development of Plant Pressurization for Environmental Qualification (DCR 9111/EC66066) | BC

5. LaSalle Station Updated Final Safety Analysis Report, Section 9.2.1, ECCS Equipment Cooling Water System (excerpt - Attachment A) * This section has since been revised. See controlled UFSAR for current values. | BO

6. LaSalle Station Updated Final Safety Analysis Report, Section 9.2.6, Ultimate Heat Sink (excerpt - Attachment A) * This section has since been revised. See controlled UFSAR for controlled value. | BO

7. Drawing Number 28SW4045~~[illegible]~~3, "CSCS Equipment Area Cooling Coils," original issue, 7/21/76 (Attachment A) 5

8. LaSalle Calculation L-000581, Revision 0, Evaluation of the CSCS Cubicle Area Coolers Operation with a Reduced Cooling Water Inlet Temperature

9. Piping and Instrumentation Drawing M-87, Sheet 3, "CSCS Equipment Cooling Water System," Revision ~~F dated 5/4/88~~ M dated 3/9/06 | BO

10. Piping and Instrumentation Drawing M-134, Sheet 3, "CSCS Equipment Cooling Water System," Revision ~~F dated 5/25/82~~ L dated 12/15/04 | BO

11. ~~Bahnson Drawings 2605-1-11,12,13, & 14 (Attachment A)~~ Vendor drawings BBC-100-13 (Unit 1) Rev 2. dated 3/31/82 and BBC-100-14 (Unit 2) Rev. 2 dated 3/31/82 | BO

12. Standards of the Tubular Exchanger Manufacturers Association (TEMA), Seventh Edition, 1988

13. Specification Number J-2582, Heat Exchange Coils and Cabinets, La Salle County - Units 1 and 2, Revision 1, dated 1/16/75 (excerpt - Attachment A) - (Historical) | B02

14. Proto-Power Calculation 96-069, Revision -, Fluid Properties - Moist Air - Range 8° to 300°F

15. *Compact Heat Exchangers*, W.M. Kays and A.L. London, McGraw Hill, Third Edition, 1984. (excerpt - Attachment C)

PROTO-POWER CORPORATION **GROTON, CONNECTICUT**	CALC NO. 97-199	REV ~~A~~ B02	PAGE 24 OF 24 FINAL
	ORIGINATOR L. Philpot		DATE 7/7/98
	VERIFIED BY M. Aboye		JOB NO. 31-003
CLIENT Commonwealth Edison	PROJECT LaSalle Station GL 89-13 Heat Exchanger Testing		
TITLE VY Cooler Thermal Performance Model -- 1(2)VY03A			

|BC

16. 1997 ASHRAE Handbook -- Fundamentals, inch pound Edition, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA (excerpt - Attachment A)

17. Drawing M-1366, Sheet 1, "Reactor Building Ventilation System -- Elevation 694'-6" East," Revision H dated 4/29/83

18. Drawing M-1464, "CSCS Equipment Cooling System," Revision ~~B dated 5/12/88~~ D dated 7/25/01 |B02

19. Drawing M-1465, "CSCS Equipment Cooling System," Revision ~~B dated 5/12/88~~ E dated 7/25/01 |B02

20. Coil Walkdown Data, ComEd NDIT No. LS-0847 dated 7/6/98 (Attachment L)

Reference 4

LSCS-UFSAR

TABLE 3.11-8

HARSH ENVIRONMENT ZONE H6 - BOUNDING ENVIRONMENTAL CONDITIONS INSIDE THE ECCS CUBICLES (EXCLUDING LPCS/RCIC CUBICLE) IN THE REACTOR BUILDING

WHEN THE ECCS EQUIPMENT IS OPERATING

The maximum cubicle temperature is 148°F, 90% relative humidity and at atmospheric pressure for the duration of 100 days. The total number of hours the cubicle is at 148°F will be ~22,110 hours (~921 days). The 100 days accident conditions are included.

Radiation: 1×10^7 rads gamma (integrated)

Pressure: -0.4 inch W.G.

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B02

1(2)VY03A

* NOTE: Ref. 4 is
Calc. L-002511 Rev. 0A.
per minor Rev. B02.
This is the basis for the
-0.4 in w.g. and the 148°F
temperature for in Table 1
of calc. 97-199. (Refer to Insert A
page 2a for further details)

NOTE: The bounding radiation dose ≥ (normal service radiation dose integrated over 40 years + accident does + 10% margin on the accident dose per IEEE 323-1974, Section 6.3.2.5).

Proto-Power Calc: 97-199
Attachment: A
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TABLE 3.11-8

B02 ~~REV. 6 - APRIL 1990~~

Reference 5

4. RHR pump seal cooler ('A' and 'B' RHR pumps only) - 20 gpm

5. LPCS pump motor cooling coil - 4 gpm

6. northwest cubicle area cooling coil - 150 gpm

7. southwest cubicle area cooling coil - 150 gpm

8. northeast cubicle area cooling coil - 200 gpm

→ 9. southeast cubicle area cooling coil - 180 gpm *

10. emergency makeup to fuel pool - 50 gpm minimum

11. containment flood - 300 gpm maximum.

b. System classifications are as shown in Section 3.2. All portions of this system are protected from the effects of tornados, missiles, pipe whip, and flooding.

c. To meet single failure criteria, the CSCS-ECWS for each unit is designed as three independent subsystems, one of which is shared between units (Drawing Nos. M-87 and M-134).

d. Strainers are provided to prevent plugging of cooled component heat transfer passages. All strainers include provisions for backwashing without significantly affecting system operation.

Organic fouling of heat transfer surfaces will be minimized by the chemical feed system which will treat the service water tunnel inlet flow with oxidizing biocides. However, the chemical feed system should not be considered auxiliary equipment required for the CSCS-ECW systems to perform their function. Therefore, the operability of the CSCS-ECW systems should not be tied to the operability of the chemical feed system. Connections and isolation valves are also provided immediately upstream and downstream of each cooled component for injection and circulation of biocidal agents, if necessary.

e. To detect leakage of radioactivity to the environment, radiation monitors are installed in the CSCS-ECWS immediately downstream of cooled components that contain radioactive fluids. The CSCS-ECWS discharge lines from these components are capable of remote manual isolation from the main control room.

f. Design of system piping and components is based on a 40-year life. Exterior surfaces of all buried system piping is protected by bituminous coatings and wrappings and provisions for cathodic protection are installed where such protection is found to be required based on electrical potential measurements. The design of all system piping includes a corrosion allowance of at least 0.08 inches.

* NOTE: This is a historical reference. The current UFSAR value for the southeast cubicle area cooling coil is 72.5 gpm

BO

Reference 6

the normally closed portions the integrity and operability are checked.

REFERENCE ONLY

UNCONTROLLED COPY

9.2.6 Ultimate Heat Sink

The ultimate heat sink (UHS) provides sufficient cooling water to permit the safe shutdown and cooldown of the station for 30 days with no makeup for both normal and accident conditions.

9.2.6.1 Design Bases

9.2.6.1.1 Safety Design Bases

The ultimate heat sink has the following design bases:

a. to provide sufficient water volume permitting a safe shutdown and cooldown of the station for 30 days with no water makeup for both normal operating and accident conditions - the maximum permissible water temperature supplied to the plant is taken as 100° F; *

b. to withstand the most severe postulated natural phenomenon as discussed in Chapter 2.0;

c. to withstand the postulated site-related incidents as discussed in Subsection 2.5.5; and

d. to provide water for fire protection equipment.

A more detailed physical description of the ultimate heat sink is provided in Sections 2.4 and 2.5.

9.2.6.1.2 Power Generation Design Bases

The ultimate heat sink, as a safety system, is not used during normal plant operations. Therefore, the ultimate heat sink has no power generation bases.

9.2.6.2 System Description

In the unlikely event that the main dike is breached, the cooling lake for the La Salle County Station is designed to hold 460 acre-feet of water with a surface area of 83 acres. This remaining water constitutes the ultimate heat sink for the station, and has a depth of approximately 5 feet and a top water elevation established at 690 feet. Figures 2.4-4 and 9.2-1 illustrate the physical layout and area capacity of the ultimate heat sink.

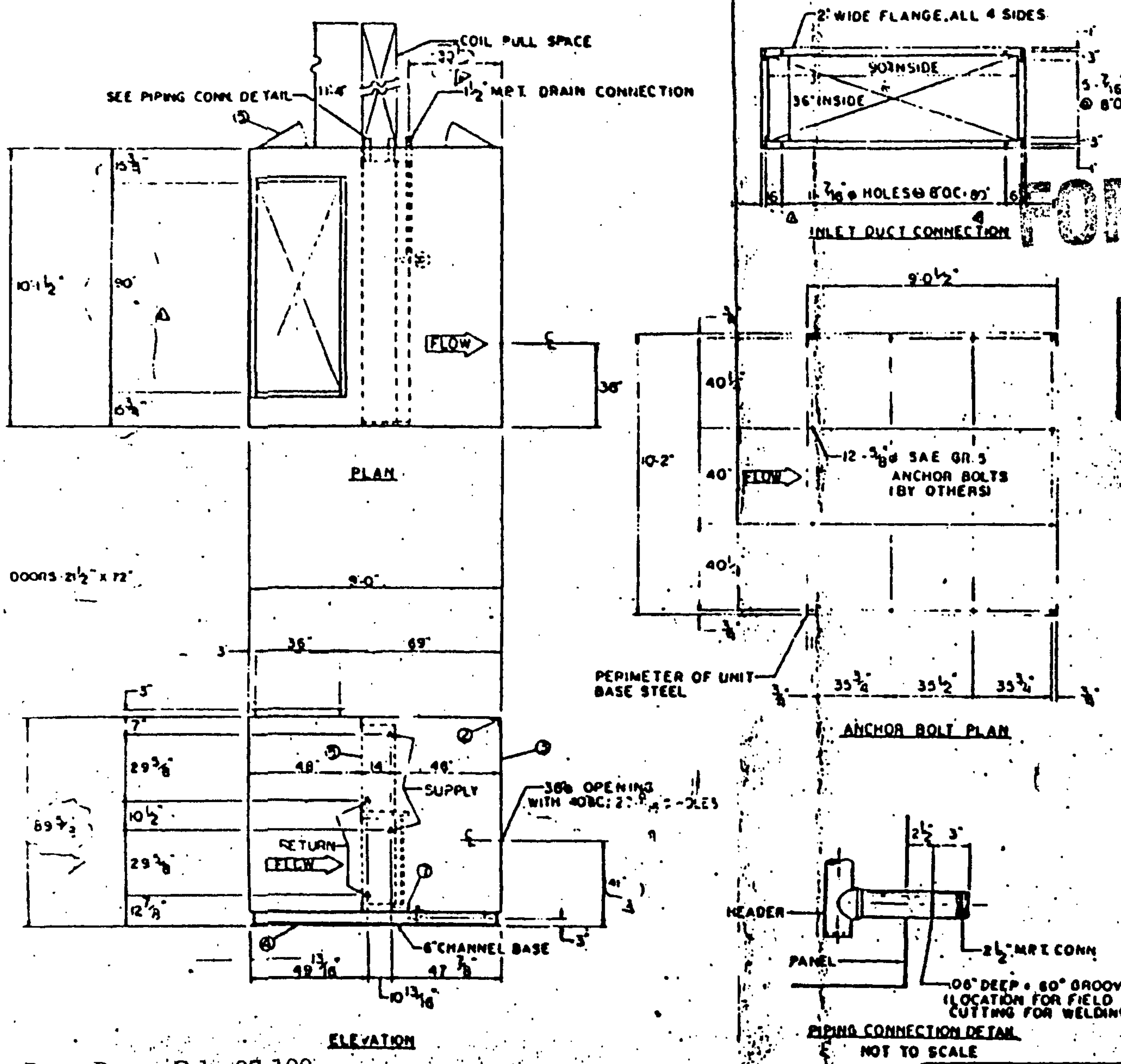
9.2.6.3 Safety Evaluation

The station's ultimate water requirements (Units 1 and 2) in gpm are summarized below.

Proto-Power Calc: 97-199
Attachment: A
Rev: ~~A~~ 302 Page 4 of 11

*NOTE: This is a section of the UFSAR which has since been revised. The current UFSAR states the UHS post-accident temperature analysis indicates a peak water supply temperature of 104°F. This has been considered in this calc, in Rev. 300.
(Ref. LUCR-92)

BC



FOR REFERENCE ONLY

SARGENT & LUNDY SPEC J-2582

SAFETY RELATED

UNCONTROLLED COPY

Reference 11

BILL OF MATERIALS

1. UNIT COOLER DESIGNED TO COOL 25,420 SCFM FROM 150/90°F TO 108.5/94°F USING 300 GPM OF WATER FROM 105°F TO 112.7°F COMPLETE WITH THE FOLLOWING CONSTRUCTION AND EQUIPMENT. FACTORY ORDER NO. 8-005IL-130.
2. GROUP OF INTERNAL STRUCTURAL FRAMING (SPEC. 3). FACTORY ORDER NO. 8-005IL-130A.
3. GROUP OF ENCLOSURE PANELS (SPEC. 3). FACTORY ORDER NO. 8-005IL-130B.
4. STRUCTURAL STEEL BASE WITH LIFTING LUGS (SPEC. 3). FACTORY ORDER NO. 8-005IL-130C.
5. ACCESS DOORS (SPEC. 4). FACTORY ORDER NO. 8-005IL-130D.
6. COOLING COILS 24 FPI 111 FT. 10 ROWS FULL CIRCUIT RATED 1,[illegible] BTUH AIR PRESSURE DROP 0.75 IN. WATER, WATER PRESSURE DROP 16 FT. WATER (SPEC. 5 & 6A). FACTORY ORDER NO. 8-005IL-130E.
7. COOLING COIL DRIP PANS CONSTRUCTED FROM 16 GAUGE 304 STAINLESS STEEL. FACTORY ORDER NO. 8-005IL-130F.

• SEE DWG 2605-15 FOR MAT'L SPECS

SHIPPING WEIGHT 7545#
OPERATING WEIGHT 7985#

LEFT HAND UNIT
ALL DIMENSIONS ± ⅛

0 1 2 3 4 5
0 6 12
GRAPHIC SCALE

LASALLE COUNTY STA UNITS 1&2
SENECA ILLINOIS
COMMONWEALTH EDISON CO

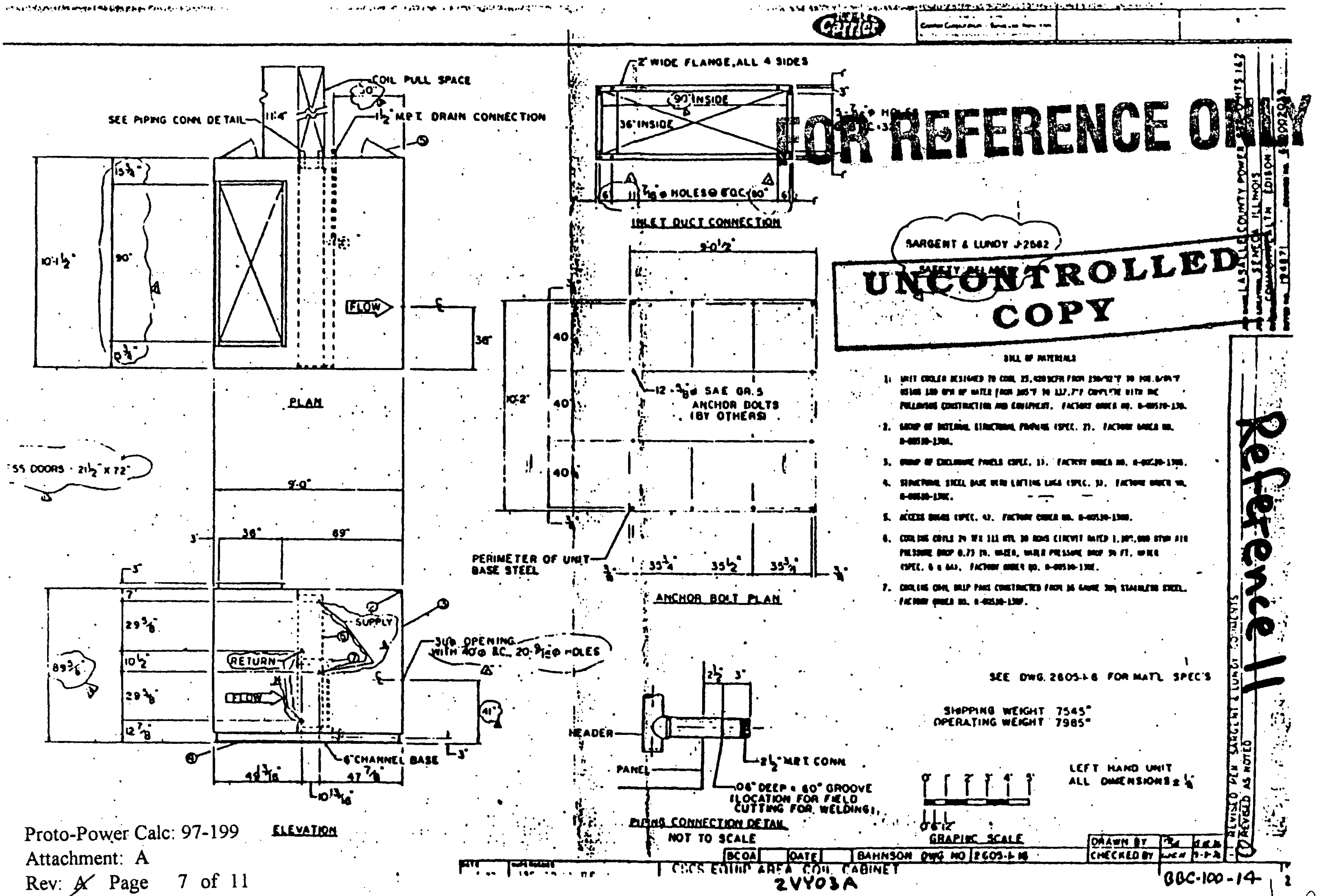
RCQA		DATE		BAHNSON DWG NO	2605-16	DRAWN BY		
						CHECKED BY		

CSCS EQUIP AREA COIL CABINET
1VY03A

BBC-100-13 2

B02

Proto-Power Calc: 97-199
Attachment: A
Rev: ~~A~~ Page 6 of 11
B02



FOR REFERENCE ONLY

SARGENT & LUNDY J-2682

UNCONTROLLED COPY

BILL OF MATERIALS

1. UNIT COOLER DESIGNED TO COOL 25,400 SCFM FROM 150/92°F TO 100.0/91°F USING 180 GPM OF WATER FROM 105°F TO 117.7°F COMPLETE WITH THE FOLLOWING CONSTRUCTION AND EQUIPMENT. FACTORY ORDER NO. 0-00510-130.
2. GROUP OF INTERNAL STRUCTURAL FRAMING (SPEC. 2). FACTORY ORDER NO. 0-00510-130A.
3. GROUP OF ENCLOSURE PANELS (SPEC. 1). FACTORY ORDER NO. 0-00510-130B.
4. STRUCTURAL STEEL BASE WITH LIFTING LUGS (SPEC. 3). FACTORY ORDER NO. 0-00510-130C.
5. ACCESS DOORS (SPEC. 4). FACTORY ORDER NO. 0-00510-130D.
6. COOLING COILS 24 FPI 111 FTL 10 ROWS CIRCUIT RATED 1,397,000 BTUH AIR PRESSURE DROP 0.73 IN. WATER, WATER PRESSURE DROP 30 FT. WATER (SPEC. 6 & 6A). FACTORY ORDER NO. 0-00510-130E.
7. COOLING COIL DRIP PANS CONSTRUCTED FROM 16 GAUGE 304 STAINLESS STEEL. FACTORY ORDER NO. 0-00510-130F.

Reference 11

SEE DWG. 2605-1-6 FOR MAT'L SPEC'S

SHIPPING WEIGHT 7545#
OPERATING WEIGHT 7985#

LEFT HAND UNIT
ALL DIMENSIONS ± ⅛"

LASALLE COUNTY POWER STATION UNITS 1&2
SENECA ILLINOIS
COMMONWEALTH EDISON
194871 ... 2002012

REVISED PER SARGENT & LUNDY COMMENTS
REVISED AS NOTED

BCOA		DATE		BAHNSON DWG NO	2605-1-16

DRAWN BY		
CHECKED BY		

CCCS EQUIP AREA COIL CABINET
2VY03A

BBC-100-14 2

B02

Proto-Power Calc: 97-199
Attachment: A
Rev: ~~A~~ Page 7 of 11
B02

CC-AA-309 - ATTACHMENT 1 - Design Analysis Approval
Page 1 of 2

DESIGN ANALYSIS NO.: Calc. #97-199 **PAGE NO.** 1
Major REV Number: B **Minor Rev Number:** 01

[ ] BRAIDWOOD STATION
[ ] BYRON STATION
[ ] CLINTON STATION
[ ] DRESDEN STATION
[X] LASALLE CO. STATION
[ ] QUAD CITIES STATION
Unit: [ ] 0 [X] 1 [X] 2 [ ] 3

DESCRIPTION CODE: (C018) M10
DISCIPLINE CODE: (C011) M
SYSTEM CODE: (C011) VY

TITLE: VY COOLER THERMAL PERFORMANCE MODEL – 1(2)VY03A

[X] Safety Related [ ] Augmented Quality [ ] Non-Safety Related

ATTRIBUTES (C016)

TYPE	VALUE	TYPE	VALUE
Elevation	694'		
Software	PROTO-HX		

COMPONENT EPN: (C014 Panel)

EPN	TYPE
1VY03A	H15
2VY03A	H15

DOCUMENT NUMBERS: (C012 Panel) (Design Analyses References)

Type/Sub	Document Number	Input (Y/N)
DCD/ EVAL	EC#337494	Y
/		
/		
/		
/		
/		
/		

REMARKS:

CC-AA-309 - ATTACHMENT 1 - Design Analysis Approval
Page 2 of 2

DESIGN ANALYSIS NO. 97-199 **REV:** B01 **PAGE NO.** 2

Revision Summary (including EC's incorporated): evaluated issues associated with 1) the impact of an error "flag" message on the printouts of Proto-Hx, which states that the Air Side Reynolds number is outside the range of equation applicability. 2) the "Data Report" output for the air coolers indicates a LOG (base 10) in the Fin Configuration equation for the Colburn 'j' factor, however the equation in the body of this calculation shows this as the natural log (Ln). The calc. has been evaluated to be acceptable as-is.

Electronic Calculation Data Files: Proto-Hx (This data is same as previous minor revision; no computer runs were performed for this minor revision)

(Program Name, Version, File Name extension/size/date/hour/min)

Design impact review completed? [ ] Yes [x] N/A, Per EC#:_337494________
(If yes, attach impact review sheet)

Prepared by: __B._L. Davenport __________ / B. L. Dav __________ / 6-[illegible]
\- Print Sign Date

Reviewed by: __D. J. Schmit__________ / D. J. Schmit __________ / 6/10/02
\- Print Sign Date

Method of Review: [✓] Detailed [ ] Alternate [ ] Test

This Design Analysis supersedes: __________N/A__________ **in its entirety.**

Supplemental Review Required? [ ] Yes [☒] No

[ ] Additional Review [ ] Special Review Team

Additional Reviewer or Special Review Team Leader: __________ / __________ / __________
\- Print Sign Date

Special Review Team: (N/A for Additional Review)

Reviewers: 1) __________ / __________ / __________ **2)** __________ / __________ / __________
\- Print Sign Date Print Sign Date

\- **3)** __________ / __________ / __________ **4)** __________ / __________ / __________
\- Print Sign Date Print Sign Date

Supplemental Review Results:

Approved by: J. T. Conner __________ / __________ / 6/12/02
\- Print Sign Date

External Design Analysis Review (Attachment 3 Attached)

Reviewed by: __________ / __________ / __________
\- Print Sign Date

Approved by: __________ / __________ / __________
\- Print Sign Date

Do any ASSUMPTIONS / ENGINEERING JUDGEMENTS require later verification? [ ] Yes [X] No
Tracked By: AT#, EC# etc.)__________

Purpose/Objective

The purpose of this minor revision is to assess the following: 1) the impact of error "flag" message on the printouts of Proto-Hx, which states that the Air Side Reynolds number is outside the range of equation applicability. An example of this flag can be found on Attachment G, page 4. 2) the "Data Report" output for the air coolers (example Attachment G, page 2) indicates a LOG (base 10) in the Fin Configuration equation for the Colburn 'j' factor, however Equation 9 of this calculation shows this as the natural log (Ln).

Methodology and Acceptance Criteria

N/A, this is an assessment of the current calculation.

Assumptions / Engineering Judgments

Assumptions and engineering judgements are documented within this analysis.

Design Inputs

N/A, this minor revision utilizes those of the current calculation.

References

1. SEAG 02-000086 (copy attached)
2. Heat Transfer-Professional Version, Lindon C. Thomas, 2nd Ed., 1999.

Analysis

1) On page 13, the Colburn 'j' factor versus Reynolds Number (Re) relationship is given. This relationship was derived in this calculation to more closely match the manufacturer's heat transfer capability. The Colburn 'j' factor relationship is based on the information in Attachment D. This attachment shows the straight line relationship between the 'j' factor and Re number when plotted on a log-log scale, with Re number end points between 1000 and 8000. This relationship was used to derive Equation 9, which is input into the computer model with the two end points. Even though the calculated Re is less than 1000 in some cases (it is normally in the range of approx. 800 to 1000), the program still uses the Equation 9 relationship with the actual Re. The computer program in this case is flagging that it had to extrapolate past the 1000 end point it was given. Reference 2, page 553 shows this relationship to be linear down to a Re of 600 for a similar type of finned tube. Based on engineering judgement, it is therefore reasonable to extrapolate this line to a somewhat lower Re down to a Reynolds number of approximately 800. Thus the results of the calculations are acceptable.

2) Equation 9 in the body of the calculation, which indicates Ln, is correct and Ln is the function being used by the program. A check of the 'j' factor numbers indicated on the computer output in the calculation show that the program is using the natural log Ln. The program manufacturer, Proto-Power, was contacted on 4-03-02. They indicated that the LOG on the Data Report represents indefinite text output and they confirmed

(FINAL)

that the program is indeed using the natural log (Ln) function for its calculations. (A letter/fax was obtained from Proto-Power on 4-03-02 confirming this discussion. The fax has been assigned file number SEAG 02-000086). A copy of this letter is attached (see Attachment A of this minor revision.

Summary and Conclusions

Based on the above discussion, the calculation results are acceptable as-is.

DESIGN ANALYSIS No. 97-199
REV. B01
ATTACHMENT A PAGE A1 OF A1

PROTO-POWER CORPORATION
A Utility Engineering Subsidiary

15 THAMES STREET
GROTON, CT 06340
PH: 860.440.9725
FX: 860.440.8292
www.protopower.com

SEAG Number

02-000086

MEMORANDUM

File No. 908SOF/050119/M02001

To: Brian Davenport

From: Joseph G. Fayan Joseph G. Fayan

Date: April 3, 2002

Subject: PROTO-HX Air Coil Module

Brian,

The PROTO-HX Data Sheet Output Report for Air Coils shows the equation for "Configuration (for Air-Side h)" with the "LOG" term in the equation. This in fact represents the "Natural Log" and not "Log Base 10." The equation actually uses the Natural Log (LN) term, however, the output report is ambiguous in printing "LOG".

If you have any other questions, please feel free to give me a call.

Sorry for the confusion.

JGF:baj

CC: Joseph G. Fayan
Job File

LASALLE CALCULATION

EDITORIAL – COMMENT TO CALCULATION

Affecting Calculation No.: 97.199	Rev: B00	For Reference	Page No. 1 of 1

The use of this form shall be limited to document corrections of editorial nature. Return to Sylvia Venecia

Prepared by:	Sylvia F. Venecia		6/3/02
	Print	Sign	Date
Reviewed by:			
	Print	Sign	Date
Approved by:			
	Print	Sign	Date

Description of Correction:

1) Pages 3 thru 6, A1, B1, C1 + D1 are on forms with the ComEd logo, which are not the most current forms.

(Per J.T. Conner on 5/28/02, OK to Process. In the future the most current forms will be used.)

When these comments are incorporated, return this form with the revised calculation.

Incorporated on Calc Rev.	By:	Date:

CC-AA-309 - ATTACHMENT 1 - Design Analysis Approval
Page 1 of 2

DESIGN ANALYSIS NO.: Calc. # 97-199 **PAGE NO.** 1

Major REV Number: B **Minor Rev Number:** 00

[ ] BRAIDWOOD STATION
[ ] BYRON STATION
[ ] CLINTON STATION
[ ] DRESDEN STATION
[X] LASALLE CO. STATION
[ ] QUAD CITIES STATION

Unit: [ ] 0 [X] 1 [X] 2 [ ] 3

DESCRIPTION CODE:(C018) M010

DISCIPLINE CODE: (C011) M

SYSTEM CODE: (C011) VY

TITLE: VY Cooler Thermal Performance Model – 1(2)VY03A

[X] Safety Related [ ] Augmented Quality [ ] Non-Safety Related

ATTRIBUTES (C016)

TYPE	VALUE	TYPE	VALUE
Elevation	694'		
Software	PROTO-HX		

COMPONENT EPN: (C014 Panel)

EPN	TYPE
1VY03A	H15
2VY03A	H15

DOCUMENT NUMBERS: (C012 Panel) (Design Analyses References)

Type/Sub	Document Number	Input (Y/N)
EC/DCP	EC# 334017	Y
/		
/		
/		
/		
/		
/		

REMARKS: NA

CC-AA-309 - ATTACHMENT 1 - Design Analysis Approval
Page 2 of 2

DESIGN ANALYSIS NO. *97-199* **REV: B00 PAGE NO. 2**

Revision Summary (including EC's incorporated): Updated ProtoHX model for 104°F Service Water inlet temperature and calculated Unit 1 and 2 B & C RHR Pump Room Cooler thermal margins for design fouling factor and 5% tubes plugged.

Electronic Calculation Data Files: ProtoHX 3.02, vy-03a.phx, 1280 KB, 4/24/2002, 5:08 pm

(Program Name, Version, File Name extension/size/date/hour/min)

Design impact review completed? [ ] Yes [X] N/A, Per EC#: 334017
(If yes, attach impact review sheet)

Prepared by: Jeff W. VanStrien / Jeff W. Vanstrien / 5-7-02
\- Print Sign Date

Reviewed by: Brian L. Davenport / / 5-10-02
\- Print Sign Date

Method of Review: [X] Detailed [ ] Alternate [ ] Test

This Design Analysis supersedes: N/A in its entirety.

Supplemental Review Required? [ ] Yes [X] No

[ ] Additional Review [ ] Special Review Team

Additional Reviewer or Special Review Team Leader: ____ / ____ / ____
\- Print Sign Date

Special Review Team: (N/A for Additional Review)

Reviewers: 1) ____ / ____ / ____ 2) ____ / ____ / ____
\- Print Sign Date Print Sign Date

3) ____ / ____ / ____ 4) ____ / ____ / ____
\- Print Sign Date Print Sign Date

Supplemental Review Results:

Approved by: J.T. Conway / / 5/14/02
\- Print Sign Date

External Design Analysis Review (Attachment 3 Attached)

Reviewed by: ____ / ____ / ____
\- Print Sign Date

Approved by: ____ / ____ / ____
\- Print Sign Date

Do any ASSUMPTIONS / ENGINEERING JUDGEMENTS require later verification? [ ] Yes [X] No
Tracked By: AT#, EC# etc.) ____

CALCULATION TABLE OF CONTENTS

CALCULATION NO. *97-199* **REV. NO. B00 PAGE NO. 3**

E-FORM

CALCULATION PAGE

1.0 PURPOSE/OBJECTIVE

The purpose of this minor revision is to revise the thermal model of the B & C RHR Pump Room Coolers (1VY03A, 2VY03A) for a 104°F Service Water inlet temperature. This assessment will evaluate the adequacy of these heat exchangers during a maximum allowable inlet service water temperature of 104°F. Also a maximum design fouling factor will be determined.

2.0 METHODOLOGY AND ACCEPTANCE CRITERIA

The existing heat exchanger model will be revised by changing the input of the "Tube Inlet Temp." from 100°F to 104°F and simulated for the following conditions: design fouling factor and design fouling factor with 5% of the tubes plugged. The acceptance criteria will be for the thermal margin at each stated condition to exceed the LaSalle design heat load of 722,217 BTU/hr (Ref. 1, table 1). Additional conservatism was built into this acceptance criteria by assuming a 5% uncertainty in the Proto-HX heat transfer calculations. The original benchmark model developed for this heat exchanger demonstrated a correlation to vendor performance specification well within this assumed 5% margin. In addition, as analyze within Reference 2, a sensitivity run will be performed with a 10% degraded airflow allowance at a service water inlet temperature of 104°F and a 5% plugging allowance.

A final case will be evaluated which determines the maximum acceptable fouling factor at which the design heat load can be accommodated including heat transfer model uncertainty and a 5% tube plugging allowance (w\ design airflow).

3.0 ASSUMPTIONS / ENGINEERING JUDGMENTS

The assumptions indicated in section 5.0 of References 1 and 2 are still valid.

4.0 DESIGN INPUTS

The design inputs consist of References 1 and 2 listed below.

5.0 REFERENCES

1. Calculation No. 97-199, Rev. A, " VY Cooler Thermal Performance Model – 1(2)VY03A."
2. Calculation No. 97-199, Rev. B, " VY Cooler Thermal Performance Model – 1(2)VY03A."

E-FORM

6.0 CALCULATIONS

The current calculation model is based on a Service Water inlet temperature of 100°F with a varying cooling water flow rates. Based on Reference 1 Calculation, the limiting flow rate for this unit is 72.5 gpm. At this flow rate, temperature and at an assumed fouling factor of 0.03734207 hr*ft^{2}*°F/BTU, the amount of heat transferred is 938,124 BTU/hr compared with a LaSalle Station Design Heat Load of 722,217 BTU/hr giving a 29.9% thermal margin (Ref. 1, Table 10).

Thermal margin is calculated by the following method:

Required Heat Load - Calculated Heat Transfer = Thermal Margin [Equation 1]

To express this as a percent of the required heat load, the following method is used:

$$\frac{ThermalM\arg in}{\mathrm{Re}quiredHeatLoad}\times 100\% = \%ThermalM\arg in$$ [Equation 2]

When the service water inlet temperature is increased to 104°F for the same limiting flow rate, but with a design fouling factor of 0.02650655 hr*ft2*°F/BTU, the heat transfer reduces to 874,052 BTU/hr which results in a 21% thermal margin over the design heat transfer rate of 722,217 BTU/hr [Attachment A]. Factoring in a 5% plugging allowance in the heat exchanger and running the model again at the design fouling factor and 104°F inlet service water temperature resulted in a 869,248 BTU/hr heat transfer rate, a 20.4% thermal margin above the design heat load [Attachment B]. Furthermore, the maximum fouling factor (at 104°F & 5% plugged) was found to be 0.005 hr*ft^{2}*°F/BTU tube-side and 0.0005 hr*ft^{2}*°F/BTU air-side (0.0888 hr*ft^{2}*°F/BTU overall) [Attachment C]. Additional conservatism explored the heat transfer effects with a 10% outlet airflow reduction, from 26,400 acfm to 23,760 acfm. This yielded a heat transfer rate of 814,593 BTU/hr (at design fouling conditions, 104°F, and 5% tube plugging allowance) resulting in a 12.8% thermal margin [Attachment D].

CALCULATION PAGE

7.0 SUMMARY AND CONCLUSIONS

The B & C RHR Pump Room Cooler Model was found to have adequate thermal margin for a maximum lake temperature of 104°F when operated at the design fouling condition. The maximum fouling factor was found to be 0.005 $hr^*ft^{2*\circ}F/BTU$ tube-side and 0.0005 $hr^*ft^{2*\circ}F/BTU$ air-side (0.0888 $hr^*ft^{2*\circ}F/BTU$ overall) while maintaining the required heat transfer rate at 104°F inlet temperature and with a 5% plugging allowance.

8.0 ATTACHMENTS:

Attachment "A" – Proto-Hx Calc. Report for 1(2)VY03A
(CSCS=104°F @ Design Fouling)
Attachment "B" – Proto-Hx Calc. Report for 1(2)VY03A
(CSCS=104°F @ Design FF, 5% Plugged)
Attachment "C" – Proto-Hx Calc. Report for 1(2)VY03A
(CSCS=104°F @ Max. Allowable FF, 5% Plugged)
Attachment "D" – Proto-Hx Calc. Report for 1(2)VY03A
(CSCS=104°F @ Design FF, 10% Reduced Airflow)

Final Page
(Last Page)

ComEd

CALCULATION NO.
97-199
REVISION NO. B00

PAGE NO. A1 of A10

Attachment "A"

Proto-Hx Calc. Report for 1(2)VY03A
(CSCS=104ºF @ Design Fouling)

E-FORM

15:54:22 **PROTO-HX 3.01 by Proto-Power Corporation (SN#663-7371)** 04/24/02

ComEd -- LaSalle

Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 @ 104 F, DESIGN FF

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

ComEd -- LaSalle
Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
VY03 @ 104 F, DESIGN FF

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	27,956.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

15:54:22 **PROTO-HX 3.01 by Proto-Power Corporation (SN#663-7371)** 04/24/02

ComEd -- LaSalle

Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 @ 104 F, DESIGN FF

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,306.85	36,020.13
Inlet Temperature (°F)	148.00	104.00
Outlet Temperature (°F)	114.18	128.32
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	10,532.34
LMTD	
Total Heat Transferred (BTU/hr)	874,052
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	874,052
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,306.85	36,020.13
Inlet Temperature (°F)	148.00	125.07
Outlet Temperature (°F)	143.47	128.32
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	145.73	126.69
Skin Temperature (°F)	132.04	129.04
Velocity ***	4,184.61	2.23
Reynold's Number	932**	17,188
Prandtl Number	0.7253	3.3969
Bulk Visc (lbm/ft·hr)	0.0491	1.2658
Skin Visc (lbm/ft·hr)		1.2394
Density (lbm/ft³)	0.0621	61.6051
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0163	0.3722

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	843.38
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.87
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.88
Effective Area (ft²)	1,053.23
LMTD	18.91
Total Heat Transferred (BTU/hr)	117,114
Surface Effectiveness (Eta)	0.9221
Sensible Heat Transferred (BTU/hr)	117,114
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 @ 104 F, DESIGN FF

Extrapolation Calculation for Row 2(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	103,306.85	36,020.13
Inlet Temperature (°F)	143.47	122.03
Outlet Temperature (°F)	139.24	125.07
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	141.36	123.55
Skin Temperature (°F)	128.56	125.77
Velocity ***	4,184.61	2.23
Reynold's Number	938**	16,702
Prandtl Number	0.7257	3.5052
Bulk Visc (lbm/ft·hr)	0.0488	1.3027
Skin Visc (lbm/ft·hr)		1.2764
Density (lbm/ft³)	0.0625	61.6559
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3712

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	830.54
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.85
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.86
Effective Area (ft²)	1,053.23
LMTD	17.69
Total Heat Transferred (BTU/hr)	109,161
Surface Effectiveness (Eta)	0.9222
Sensible Heat Transferred (BTU/hr)	109,161
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	103,306.85	36,020.13
Inlet Temperature (°F)	139.24	119.20
Outlet Temperature (°F)	135.31	122.03
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	137.27	120.62
Skin Temperature (°F)	125.32	122.72
Velocity ***	4,184.61	2.23
Reynold's Number	942**	16,252
Prandtl Number	0.7261	3.6115
Bulk Visc (lbm/ft·hr)	0.0486	1.3387
Skin Visc (lbm/ft·hr)		1.3127
Density (lbm/ft³)	0.0629	61.7021
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3702

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	818.52
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.83
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.84
Effective Area (ft²)	1,053.23
LMTD	16.55
Total Heat Transferred (BTU/hr)	101,788
Surface Effectiveness (Eta)	0.9224
Sensible Heat Transferred (BTU/hr)	101,788
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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VY03 @ 104 F, DESIGN FF

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,306.85	36,020.13
Inlet Temperature (°F)	135.31	116.56
Outlet Temperature (°F)	131.63	119.20
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	133.47	117.88
Skin Temperature (°F)	122.30	119.87
Velocity ***	4,184.61	2.23
Reynold's Number	947**	15,837
Prandtl Number	0.7264	3.7154
Bulk Visc (lbm/ft·hr)	0.0483	1.3738
Skin Visc (lbm/ft·hr)		1.3481
Density (lbm/ft³)	0.0633	61.7442
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3693

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	807.26
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.81
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.82
Effective Area (ft²)	1,053.23
LMTD	15.48
Total Heat Transferred (BTU/hr)	94,950
Surface Effectiveness (Eta)	0.9225
Sensible Heat Transferred (BTU/hr)	94,950
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,306.85	36,020.13
Inlet Temperature (°F)	131.63	114.10
Outlet Temperature (°F)	128.20	116.56
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	129.92	115.33
Skin Temperature (°F)	119.48	117.21
Velocity ***	4,184.61	2.23
Reynold's Number	951**	15,453
Prandtl Number	0.7267	3.8168
Bulk Visc (lbm/ft·hr)	0.0481	1.4079
Skin Visc (lbm/ft·hr)		1.3826
Density (lbm/ft³)	0.0637	61.7826
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3684

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	796.71
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.79
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.81
Effective Area (ft²)	1,053.23
LMTD	14.49
Total Heat Transferred (BTU/hr)	88,602
Surface Effectiveness (Eta)	0.9226
Sensible Heat Transferred (BTU/hr)	88,602
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec): Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,306.85	36,020.13
Inlet Temperature (°F)	128.20	111.80
Outlet Temperature (°F)	125.00	114.10
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	126.60	112.95
Skin Temperature (°F)	116.84	114.73
Velocity ***	4,184.61	2.23
Reynold's Number	956**	15,097
Prandtl Number	0.7269	3.9156
Bulk Visc (lbm/ft·hr)	0.0479	1.4411
Skin Visc (lbm/ft·hr)		1.4162
Density (lbm/ft³)	0.0640	61.8177
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3676

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	786.83
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.78
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.79
Effective Area (ft²)	1,053.23
LMTD	13.56
Total Heat Transferred (BTU/hr)	82,706
Surface Effectiveness (Eta)	0.9228
Sensible Heat Transferred (BTU/hr)	82,706
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,306.85	36,020.13
Inlet Temperature (°F)	125.00	109.65
Outlet Temperature (°F)	122.01	111.80
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	123.51	110.73
Skin Temperature (°F)	114.38	112.40
Velocity ***	4,184.61	2.22
Reynold's Number	959**	14,768
Prandtl Number	0.7272	4.0117
Bulk Visc (lbm/ft·hr)	0.0477	1.4732
Skin Visc (lbm/ft·hr)		1.4489
Density (lbm/ft³)	0.0643	61.8497
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3668

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	777.57
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.76
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.77
Effective Area (ft²)	1,053.23
LMTD	12.70
Total Heat Transferred (BTU/hr)	77,227
Surface Effectiveness (Eta)	0.9229
Sensible Heat Transferred (BTU/hr)	77,227
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
VY03 @ 104 F, DESIGN FF

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,306.85	36,020.13
Inlet Temperature (°F)	122.01	107.65
Outlet Temperature (°F)	119.22	109.65
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	120.62	108.65
Skin Temperature (°F)	112.08	110.24
Velocity ***	4,184.61	2.22
Reynold's Number	963**	14,462
Prandtl Number	0.7274	4.1049
Bulk Visc (lbm/ft·hr)	0.0475	1.5043
Skin Visc (lbm/ft·hr)		1.4805
Density (lbm/ft³)	0.0647	61.8790
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3660

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	768.90
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.75
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.76
Effective Area (ft²)	1,053.23
LMTD	11.89
Total Heat Transferred (BTU/hr)	72,132
Surface Effectiveness (Eta)	0.9230
Sensible Heat Transferred (BTU/hr)	72,132
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,306.85	36,020.13
Inlet Temperature (°F)	119.22	105.78
Outlet Temperature (°F)	116.62	107.65
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	117.92	106.71
Skin Temperature (°F)	109.93	108.21
Velocity ***	4,184.61	2.22
Reynold's Number	967**	14,179
Prandtl Number	0.7275	4.1952
Bulk Visc (lbm/ft·hr)	0.0474	1.5344
Skin Visc (lbm/ft·hr)		1.5111
Density (lbm/ft³)	0.0649	61.9058
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3653

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	760.77
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.74
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.75
Effective Area (ft²)	1,053.23
LMTD	11.13
Total Heat Transferred (BTU/hr)	67,393
Surface Effectiveness (Eta)	0.9231
Sensible Heat Transferred (BTU/hr)	67,393
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
VY03 @ 104 F, DESIGN FF

Extrapolation Calculation for Row 10(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	103,306.85	36,020.13
Inlet Temperature (°F)	116.62	104.03
Outlet Temperature (°F)	114.18	105.78
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	115.40	104.90
Skin Temperature (°F)	107.93	106.31
Velocity ***	4,184.61	2.22
Reynold's Number	970**	13,916
Prandtl Number	0.7277	4.2825
Bulk Visc (lbm/ft·hr)	0.0472	1.5634
Skin Visc (lbm/ft·hr)		1.5407
Density (lbm/ft³)	0.0652	61.9303
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3647

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	753.16
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.73
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.73
Effective Area (ft²)	1,053.23
LMTD	10.43
Total Heat Transferred (BTU/hr)	62,981
Surface Effectiveness (Eta)	0.9232
Sensible Heat Transferred (BTU/hr)	62,981
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Inlet Air Flowrate Calculator - 1(2)VY03A

Total P:	P=		14.315	psia
Dry Bulb T OUT:	T=		114.18	F
Specific Hum.:	W =		0.020273629	
H2O Vap P:	Pv = (W*Rv*P)/(Ra+(W*Rv) =		0.451874527	psia
		Rv =	85.778	(ft-lbf)/(lbm-R)
		Ra =	53.352	(ft-lbf)/(lbm-R)
Dry Air P:	Pa = P - Pv =		13.86312547	psia
Dry Air rho OUT:	rho a = (144/Ra)*(Pa/(459.67+T) =		0.0652	lbm/ft^3
Dry Air rho IN:	rho a = (144/Ra)*(Pa/(459.67+T) =		0.061575	lbm/ft^3
Dry Bulb T IN:	T=		148	F
Outlet Air Flow:	V =		26400	cfm

Inlet Air Flow
27956 acfm

Attachment "B"

Proto-Hx Calc. Report for 1(2)VY03A
(CSCS=104°F @ Design FF, 5% Plugged)

E-FORM

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Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 @ 104 F, 5% PLUG, DESIGN FF

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	23.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 @ 104 F, 5% PLUG, DESIGN FF

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	27,948.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 @ 104 F, 5% PLUG, DESIGN FF

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,277.29	36,020.13	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	148.00	104.00	j Factor	
Outlet Temperature (°F)	114.35	128.15	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.02650655
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	10,093.49
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	869,248
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	869,248
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,277.29	36,020.13	Tube-Side hi (BTU/hr·ft²·°F)	871.94
Inlet Temperature (°F)	148.00	124.93	j Factor	0.0070
Outlet Temperature (°F)	143.51	128.15	Air-Side ho (BTU/hr·ft²·°F)	9.12
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02650655
Average Temp (°F)	145.76	126.54		
Skin Temperature (°F)	131.98	128.88	U Overall (BTU/hr·ft²·°F)	6.01
Velocity ***	4,365.29	2.33	Effective Area (ft²)	1,009.35
Reynold's Number	973**	17,910	LMTD	19.09
Prandtl Number	0.7253	3.4021	Total Heat Transferred (BTU/hr)	115,887
Bulk Visc (lbm/ft·hr)	0.0491	1.2676		
Skin Visc (lbm/ft·hr)		1.2411	Surface Effectiveness (Eta)	0.9201
Density (lbm/ft³)	0.0620	61.6076	Sensible Heat Transferred (BTU/hr)	115,887
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3722	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

15:35:39 **PROTO-HX 3.01 by Proto-Power Corporation (SN#663-7371)** 04/24/02

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 @ 104 F, 5% PLUG, DESIGN FF

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,277.29	36,020.13
Inlet Temperature (°F)	143.51	121.92
Outlet Temperature (°F)	139.33	124.93
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	141.42	123.42
Skin Temperature (°F)	128.53	125.64
Velocity ***	4,365.29	2.33
Reynold's Number	978**	17,408
Prandtl Number	0.7257	3.5096
Bulk Visc (lbm/ft·hr)	0.0488	1.3041
Skin Visc (lbm/ft·hr)		1.2779
Density (lbm/ft^3)	0.0625	61.6578
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3712

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	858.79
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	9.10
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	5.99
Effective Area (ft^2)	1,009.35
LMTD	17.88
Total Heat Transferred (BTU/hr)	108,159
Surface Effectiveness (Eta)	0.9203
Sensible Heat Transferred (BTU/hr)	108,159
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,277.29	36,020.13
Inlet Temperature (°F)	139.33	119.11
Outlet Temperature (°F)	135.42	121.92
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	137.37	120.52
Skin Temperature (°F)	125.32	122.62
Velocity ***	4,365.29	2.33
Reynold's Number	983**	16,943
Prandtl Number	0.7261	3.6151
Bulk Visc (lbm/ft·hr)	0.0486	1.3399
Skin Visc (lbm/ft·hr)		1.3139
Density (lbm/ft^3)	0.0629	61.7036
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3702

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	846.45
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	9.08
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	5.97
Effective Area (ft^2)	1,009.35
LMTD	16.75
Total Heat Transferred (BTU/hr)	100,984
Surface Effectiveness (Eta)	0.9204
Sensible Heat Transferred (BTU/hr)	100,984
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 @ 104 F, 5% PLUG, DESIGN FF

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,277.29	36,020.13
Inlet Temperature (°F)	135.42	116.49
Outlet Temperature (°F)	131.77	119.11
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	133.59	117.80
Skin Temperature (°F)	122.31	119.79
Velocity ***	4,365.29	2.33
Reynold's Number	988**	16,513
Prandtl Number	0.7264	3.7184
Bulk Visc (lbm/ft·hr)	0.0483	1.3748
Skin Visc (lbm/ft·hr)		1.3491
Density (lbm/ft^3)	0.0633	61.7454
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3693

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	834.89
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	9.06
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	5.96
Effective Area (ft^2)	1,009.35
LMTD	15.69
Total Heat Transferred (BTU/hr)	94,320
Surface Effectiveness (Eta)	0.9205
Sensible Heat Transferred (BTU/hr)	94,320
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,277.29	36,020.13
Inlet Temperature (°F)	131.77	114.04
Outlet Temperature (°F)	128.36	116.49
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	130.06	115.27
Skin Temperature (°F)	119.51	117.15
Velocity ***	4,365.29	2.32
Reynold's Number	992**	16,115
Prandtl Number	0.7267	3.8194
Bulk Visc (lbm/ft·hr)	0.0481	1.4088
Skin Visc (lbm/ft·hr)		1.3834
Density (lbm/ft^3)	0.0636	61.7836
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3684

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	824.04
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	9.04
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	5.94
Effective Area (ft^2)	1,009.35
LMTD	14.70
Total Heat Transferred (BTU/hr)	88,125
Surface Effectiveness (Eta)	0.9207
Sensible Heat Transferred (BTU/hr)	88,125
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 @ 104 F, 5% PLUG, DESIGN FF

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,277.29	36,020.13
Inlet Temperature (°F)	128.36	111.75
Outlet Temperature (°F)	125.17	114.04
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	126.76	112.90
Skin Temperature (°F)	116.88	114.68
Velocity ***	4,365.29	2.32
Reynold's Number	997**	15,745
Prandtl Number	0.7269	3.9178
Bulk Visc (lbm/ft·hr)	0.0479	1.4418
Skin Visc (lbm/ft·hr)		1.4168
Density (lbm/ft^3)	0.0640	61.8184
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3676

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	813.86
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	9.03
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	5.92
Effective Area (ft^2)	1,009.35
LMTD	13.78
Total Heat Transferred (BTU/hr)	82,364
Surface Effectiveness (Eta)	0.9208
Sensible Heat Transferred (BTU/hr)	82,364
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,277.29	36,020.13
Inlet Temperature (°F)	125.17	109.61
Outlet Temperature (°F)	122.19	111.75
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	123.68	110.68
Skin Temperature (°F)	114.43	112.37
Velocity ***	4,365.29	2.32
Reynold's Number	1,001	15,403
Prandtl Number	0.7272	4.0136
Bulk Visc (lbm/ft·hr)	0.0477	1.4739
Skin Visc (lbm/ft·hr)		1.4494
Density (lbm/ft^3)	0.0643	61.8503
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3668

Tube-Side hi (BTU/hr·ft^2·°F)	804.32
j Factor	0.0069
Air-Side ho (BTU/hr·ft^2·°F)	9.01
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	5.91
Effective Area (ft^2)	1,009.35
LMTD	12.91
Total Heat Transferred (BTU/hr)	77,003
Surface Effectiveness (Eta)	0.9209
Sensible Heat Transferred (BTU/hr)	77,003
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 @ 104 F, 5% PLUG, DESIGN FF

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,277.29	36,020.13
Inlet Temperature (°F)	122.19	107.61
Outlet Temperature (°F)	119.40	109.61
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	120.80	108.61
Skin Temperature (°F)	112.13	110.21
Velocity ***	4,365.29	2.32
Reynold's Number	1,005	15,085
Prandtl Number	0.7274	4.1067
Bulk Visc (lbm/ft·hr)	0.0475	1.5049
Skin Visc (lbm/ft·hr)		1.4809
Density (lbm/ft³)	0.0646	61.8795
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3660

Tube-Side hi (BTU/hr·ft²·°F)	795.37
j Factor	0.0069
Air-Side ho (BTU/hr·ft²·°F)	9.00
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.89
Effective Area (ft²)	1,009.35
LMTD	12.11
Total Heat Transferred (BTU/hr)	72,012
Surface Effectiveness (Eta)	0.9210
Sensible Heat Transferred (BTU/hr)	72,012
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,277.29	36,020.13
Inlet Temperature (°F)	119.40	105.74
Outlet Temperature (°F)	116.79	107.61
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	118.10	106.68
Skin Temperature (°F)	109.98	108.18
Velocity ***	4,365.29	2.32
Reynold's Number	1,008	14,790
Prandtl Number	0.7275	4.1970
Bulk Visc (lbm/ft·hr)	0.0474	1.5350
Skin Visc (lbm/ft·hr)		1.5115
Density (lbm/ft³)	0.0649	61.9063
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3653

Tube-Side hi (BTU/hr·ft²·°F)	786.98
j Factor	0.0069
Air-Side ho (BTU/hr·ft²·°F)	8.99
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.88
Effective Area (ft²)	1,009.35
LMTD	11.35
Total Heat Transferred (BTU/hr)	67,363
Surface Effectiveness (Eta)	0.9211
Sensible Heat Transferred (BTU/hr)	67,363
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,277.29	36,020.13
Inlet Temperature (°F)	116.79	103.99
Outlet Temperature (°F)	114.35	105.74
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	115.57	104.86
Skin Temperature (°F)	107.97	106.29
Velocity ***	4,365.29	2.32
Reynold's Number	1,012	14,515
Prandtl Number	0.7277	4.2844
Bulk Visc (lbm/ft·hr)	0.0472	1.5640
Skin Visc (lbm/ft·hr)		1.5411
Density (lbm/ft³)	0.0652	61.9308
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3646

Tube-Side hi (BTU/hr·ft²·°F)	779.10
j Factor	0.0069
Air-Side ho (BTU/hr·ft²·°F)	8.97
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.87
Effective Area (ft²)	1,009.35
LMTD	10.64
Total Heat Transferred (BTU/hr)	63,031
Surface Effectiveness (Eta)	0.9212
Sensible Heat Transferred (BTU/hr)	63,031
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Inlet Air Flowrate Calculator - 1(2)VY03A

Total P:	P=		14.315	psia	Inlet Air Flow
Dry Bulb T OUT:	T=		114.35	F	27948 acfm
Specific Hum.:	W =		0.020273629		
H2O Vap P:	Pv = (W*Rv*P)/(Ra+(W*Rv) =		0.451874527	psia	
		Rv =	85.778	(ft-lbf)/(lbm-R)	
		Ra =	53.352	(ft-lbf)/(lbm-R)	
Dry Air P:	Pa = P - Pv =		13.86312547	psia	
Dry Air rho OUT:	rho a = (144/Ra)*(Pa/(459.67+T) =		0.0652	lbm/ft^3	
Dry Air rho IN:	rho a = (144/Ra)*(Pa/(459.67+T) =		0.061575	lbm/ft^3	
Dry Bulb T IN:	T=		148	F	
Outlet Air Flow:	V =		26400	cfm	

Attachment "C"

Proto-Hx Calc. Report for 1(2)VY03A
(CSCS=104°F @ Max. Allowable FF, w\5% plugged)

E-FORM

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Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
VY03 @ 104 F, 5% PLUG, MAX FF

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.005000
Air-Side Fouling	0.000500
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A
	j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	23.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	27,779.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 @ 104 F, 5% PLUG, MAX FF

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	102,652.78	36,020.13	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	148.00	104.00	j Factor	
Outlet Temperature (°F)	117.83	125.53	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.08885517
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	10,093.49
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	774,686
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	774,686
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	102,652.78	36,020.13	Tube-Side hi (BTU/hr·ft²·°F)	861.71
Inlet Temperature (°F)	148.00	122.85	j Factor	0.0070
Outlet Temperature (°F)	144.25	125.53	Air-Side ho (BTU/hr·ft²·°F)	9.08
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.08885517
Average Temp (°F)	146.13	124.19		
Skin Temperature (°F)	134.68	126.15	U Overall (BTU/hr·ft²·°F)	4.36
Velocity ***	4,338.90	2.33	Effective Area (ft²)	1,009.35
Reynold's Number	966**	17,531	LMTD	21.86
Prandtl Number	0.7253	3.4827	Total Heat Transferred (BTU/hr)	96,218
Bulk Visc (lbm/ft·hr)	0.0491	1.2950		
Skin Visc (lbm/ft·hr)		1.2720	Surface Effectiveness (Eta)	0.9204
Density (lbm/ft³)	0.0620	61.6456	Sensible Heat Transferred (BTU/hr)	96,218
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3714	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,652.78	36,020.13
Inlet Temperature (°F)	144.25	120.31
Outlet Temperature (°F)	140.69	122.85
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	142.47	121.58
Skin Temperature (°F)	131.58	123.47
Velocity ***	4,338.90	2.33
Reynold's Number	971**	17,113
Prandtl Number	0.7256	3.5759
Bulk Visc (lbm/ft·hr)	0.0489	1.3266
Skin Visc (lbm/ft·hr)		1.3036
Density (lbm/ft^3)	0.0623	61.6870
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3706

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	850.70
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	9.06
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.08885517
U Overall (BTU/hr·ft^2·°F)	4.35
Effective Area (ft^2)	1,009.35
LMTD	20.82
Total Heat Transferred (BTU/hr)	91,443
Surface Effectiveness (Eta)	0.9205
Sensible Heat Transferred (BTU/hr)	91,443
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,652.78	36,020.13
Inlet Temperature (°F)	140.69	117.90
Outlet Temperature (°F)	137.31	120.31
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	139.00	119.10
Skin Temperature (°F)	128.62	120.92
Velocity ***	4,338.90	2.33
Reynold's Number	975**	16,719
Prandtl Number	0.7259	3.6683
Bulk Visc (lbm/ft·hr)	0.0487	1.3579
Skin Visc (lbm/ft·hr)		1.3348
Density (lbm/ft^3)	0.0627	61.7255
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3697

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	840.18
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	9.05
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.08885517
U Overall (BTU/hr·ft^2·°F)	4.34
Effective Area (ft^2)	1,009.35
LMTD	19.83
Total Heat Transferred (BTU/hr)	86,919
Surface Effectiveness (Eta)	0.9206
Sensible Heat Transferred (BTU/hr)	86,919
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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VY03 @ 104 F, 5% PLUG, MAX FF

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,652.78	36,020.13
Inlet Temperature (°F)	137.31	115.60
Outlet Temperature (°F)	134.09	117.90
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	135.70	116.75
Skin Temperature (°F)	125.82	118.50
Velocity ***	4,338.90	2.32
Reynold's Number	979**	16,347
Prandtl Number	0.7262	3.7599
Bulk Visc (lbm/ft·hr)	0.0485	1.3888
Skin Visc (lbm/ft·hr)		1.3658
Density (lbm/ft³)	0.0630	61.7614
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3689

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	830.15
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	9.03
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.08885517
U Overall (BTU/hr·ft²·°F)	4.33
Effective Area (ft²)	1,009.35
LMTD	18.89
Total Heat Transferred (BTU/hr)	82,633
Surface Effectiveness (Eta)	0.9208
Sensible Heat Transferred (BTU/hr)	82,633
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,652.78	36,020.13
Inlet Temperature (°F)	134.09	113.41
Outlet Temperature (°F)	131.03	115.60
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	132.56	114.51
Skin Temperature (°F)	123.15	116.19
Velocity ***	4,338.90	2.32
Reynold's Number	983**	15,996
Prandtl Number	0.7265	3.8505
Bulk Visc (lbm/ft·hr)	0.0483	1.4193
Skin Visc (lbm/ft·hr)		1.3963
Density (lbm/ft³)	0.0634	61.7948
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3681

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	820.59
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	9.02
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.08885517
U Overall (BTU/hr·ft²·°F)	4.33
Effective Area (ft²)	1,009.35
LMTD	17.99
Total Heat Transferred (BTU/hr)	78,570
Surface Effectiveness (Eta)	0.9209
Sensible Heat Transferred (BTU/hr)	78,570
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03 @ 104 F, 5% PLUG, MAX FF

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,652.78	36,020.13
Inlet Temperature (°F)	131.03	111.34
Outlet Temperature (°F)	128.12	113.41
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	129.57	112.38
Skin Temperature (°F)	120.62	113.99
Velocity ***	4,338.90	2.32
Reynold's Number	987**	15,665
Prandtl Number	0.7267	3.9401
Bulk Visc (lbm/ft·hr)	0.0481	1.4493
Skin Visc (lbm/ft·hr)		1.4264
Density (lbm/ft³)	0.0637	61.8260
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3674

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	811.46
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	9.00
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.08885517
U Overall (BTU/hr·ft²·°F)	4.32
Effective Area (ft²)	1,009.35
LMTD	17.14
Total Heat Transferred (BTU/hr)	74,719
Surface Effectiveness (Eta)	0.9210
Sensible Heat Transferred (BTU/hr)	74,719
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,652.78	36,020.13
Inlet Temperature (°F)	128.12	109.36
Outlet Temperature (°F)	125.35	111.34
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	126.74	110.35
Skin Temperature (°F)	118.20	111.91
Velocity ***	4,338.90	2.32
Reynold's Number	991**	15,352
Prandtl Number	0.7269	4.0284
Bulk Visc (lbm/ft·hr)	0.0479	1.4788
Skin Visc (lbm/ft·hr)		1.4561
Density (lbm/ft³)	0.0640	61.8551
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3667

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	802.75
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.99
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.08885517
U Overall (BTU/hr·ft²·°F)	4.31
Effective Area (ft²)	1,009.35
LMTD	16.33
Total Heat Transferred (BTU/hr)	71,067
Surface Effectiveness (Eta)	0.9211
Sensible Heat Transferred (BTU/hr)	71,067
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

VY03 @ 104 F, 5% PLUG, MAX FF

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,652.78	36,020.13
Inlet Temperature (°F)	125.35	107.48
Outlet Temperature (°F)	122.72	109.36
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	124.04	108.42
Skin Temperature (°F)	115.91	109.92
Velocity ***	4,338.90	2.32
Reynold's Number	994**	15,056
Prandtl Number	0.7271	4.1154
Bulk Visc (lbm/ft·hr)	0.0477	1.5078
Skin Visc (lbm/ft·hr)		1.4852
Density (lbm/ft³)	0.0643	61.8822
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0158	0.3660

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	794.45
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.98
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.08885517
U Overall (BTU/hr·ft²·°F)	4.30
Effective Area (ft²)	1,009.35
LMTD	15.56
Total Heat Transferred (BTU/hr)	67,603
Surface Effectiveness (Eta)	0.9212
Sensible Heat Transferred (BTU/hr)	67,603
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,652.78	36,020.13
Inlet Temperature (°F)	122.72	105.70
Outlet Temperature (°F)	120.22	107.48
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	121.47	106.59
Skin Temperature (°F)	113.73	108.03
Velocity ***	4,338.90	2.32
Reynold's Number	998**	14,777
Prandtl Number	0.7273	4.2010
Bulk Visc (lbm/ft·hr)	0.0476	1.5363
Skin Visc (lbm/ft·hr)		1.5139
Density (lbm/ft³)	0.0645	61.9075
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3653

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	786.53
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.97
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.08885517
U Overall (BTU/hr·ft²·°F)	4.30
Effective Area (ft²)	1,009.35
LMTD	14.83
Total Heat Transferred (BTU/hr)	64,316
Surface Effectiveness (Eta)	0.9213
Sensible Heat Transferred (BTU/hr)	64,316
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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VY03 @ 104 F, 5% PLUG, MAX FF

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,652.78	36,020.13
Inlet Temperature (°F)	120.22	103.99
Outlet Temperature (°F)	117.83	105.70
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	119.02	104.85
Skin Temperature (°F)	111.65	106.23
Velocity ***	4,338.90	2.32
Reynold's Number	1,001	14,513
Prandtl Number	0.7275	4.2852
Bulk Visc (lbm/ft·hr)	0.0474	1.5643
Skin Visc (lbm/ft·hr)		1.5421
Density (lbm/ft³)	0.0648	61.9311
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3646

Tube-Side hi (BTU/hr·ft²·°F)	778.97
j Factor	0.0069
Air-Side ho (BTU/hr·ft²·°F)	8.95
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.08885517
U Overall (BTU/hr·ft²·°F)	4.29
Effective Area (ft²)	1,009.35
LMTD	14.13
Total Heat Transferred (BTU/hr)	61,198
Surface Effectiveness (Eta)	0.9214
Sensible Heat Transferred (BTU/hr)	61,198
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Inlet Air Flowrate Calculator - 1(2)VY03A

Total P:	P=		14.315	psia	Inlet Air Flow
Dry Bulb T OUT:	T=		117.83	F	27779 acfm
Specific Hum.:	W =		0.020273629		
H2O Vap P:	Pv = (W*Rv*P)/(Ra+(W*Rv) =		0.451874527	psia	
		Rv =	85.778	(ft-lbf)/(lbm-R)	
		Ra =	53.352	(ft-lbf)/(lbm-R)	
Dry Air P:	Pa = P - Pv =		13.86312547	psia	
Dry Air rho OUT:	rho a = (144/Ra)*(Pa/(459.67+T) =		0.0648	lbm/ft^3	
Dry Air rho IN:	rho a = (144/Ra)*(Pa/(459.67+T) =		0.061575	lbm/ft^3	
Dry Bulb T IN:	T=		148	F	
Outlet Air Flow:	V =		26400	cfm	

Attachment "D"

Proto-Hx Calc. Report for 1(2)VY03A
(CSCS=104ºF @ Design FF, 10% Reduced Airflow)

E-FORM

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Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
VY03@104 F, 5%PLUG, 10%REDUCED

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	23.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	25,210.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03@104 F, 5%PLUG, 10%REDUCED

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	93,159.45	36,020.13	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	148.00	104.00	j Factor	
Outlet Temperature (°F)	113.05	126.64	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	10,093.49
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	814,593
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	814,593
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	93,159.45	36,020.13	Tube-Side hi (BTU/hr·ft^2·°F)	865.61
Inlet Temperature (°F)	148.00	123.37	j Factor	0.0073
Outlet Temperature (°F)	142.95	126.64	Air-Side ho (BTU/hr·ft^2·°F)	8.52
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
Average Temp (°F)	145.47	125.01		
Skin Temperature (°F)	130.56	127.41	U Overall (BTU/hr·ft^2·°F)	5.74
Velocity ***	3,937.64	2.33	Effective Area (ft^2)	1,009.35
Reynold's Number	878**	17,663	LMTD	20.32
Prandtl Number	0.7253	3.4543	Total Heat Transferred (BTU/hr)	117,794
Bulk Visc (lbm/ft·hr)	0.0491	1.2853		
Skin Visc (lbm/ft·hr)		1.2576	Surface Effectiveness (Eta)	0.9248
Density (lbm/ft^3)	0.0621	61.6324	Sensible Heat Transferred (BTU/hr)	117,794
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3717	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

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Attachment D
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*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,159.45	36,020.13
Inlet Temperature (°F)	142.95	120.38
Outlet Temperature (°F)	138.33	123.37
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	140.64	121.87
Skin Temperature (°F)	126.98	124.10
Velocity ***	3,937.64	2.33
Reynold's Number	883**	17,160
Prandtl Number	0.7258	3.5652
Bulk Visc (lbm/ft·hr)	0.0488	1.3230
Skin Visc (lbm/ft·hr)		1.2960
Density (lbm/ft³)	0.0626	61.6824
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3707

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	852.29
j Factor	0.0073
Air-Side ho (BTU/hr·ft²·°F)	8.50
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.72
Effective Area (ft²)	1,009.35
LMTD	18.63
Total Heat Transferred (BTU/hr)	107,614
Surface Effectiveness (Eta)	0.9250
Sensible Heat Transferred (BTU/hr)	107,614
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,159.45	36,020.13
Inlet Temperature (°F)	138.33	117.65
Outlet Temperature (°F)	134.11	120.38
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	136.22	119.01
Skin Temperature (°F)	123.71	121.08
Velocity ***	3,937.64	2.33
Reynold's Number	888**	16,704
Prandtl Number	0.7262	3.6718
Bulk Visc (lbm/ft·hr)	0.0485	1.3591
Skin Visc (lbm/ft·hr)		1.3329
Density (lbm/ft³)	0.0630	61.7269
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3697

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	840.07
j Factor	0.0072
Air-Side ho (BTU/hr·ft²·°F)	8.48
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.70
Effective Area (ft²)	1,009.35
LMTD	17.09
Total Heat Transferred (BTU/hr)	98,368
Surface Effectiveness (Eta)	0.9252
Sensible Heat Transferred (BTU/hr)	98,368
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03@104 F, 5%PLUG, 10%REDUCED

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,159.45	36,020.13
Inlet Temperature (°F)	134.11	115.14
Outlet Temperature (°F)	130.25	117.65
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	132.18	116.39
Skin Temperature (°F)	120.71	118.31
Velocity ***	3,937.64	2.32
Reynold's Number	893**	16,291
Prandtl Number	0.7265	3.7740
Bulk Visc (lbm/ft·hr)	0.0483	1.3935
Skin Visc (lbm/ft·hr)		1.3682
Density (lbm/ft³)	0.0634	61.7667
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3688

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	828.84
j Factor	0.0072
Air-Side ho (BTU/hr·ft²·°F)	8.46
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.69
Effective Area (ft²)	1,009.35
LMTD	15.68
Total Heat Transferred (BTU/hr)	89,961
Surface Effectiveness (Eta)	0.9253
Sensible Heat Transferred (BTU/hr)	89,961
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,159.45	36,020.13
Inlet Temperature (°F)	130.25	112.86
Outlet Temperature (°F)	126.71	115.14
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	128.48	114.00
Skin Temperature (°F)	117.97	115.77
Velocity ***	3,937.64	2.32
Reynold's Number	897**	15,917
Prandtl Number	0.7268	3.8715
Bulk Visc (lbm/ft·hr)	0.0480	1.4263
Skin Visc (lbm/ft·hr)		1.4019
Density (lbm/ft³)	0.0638	61.8023
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3680

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	818.54
j Factor	0.0072
Air-Side ho (BTU/hr·ft²·°F)	8.44
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.67
Effective Area (ft²)	1,009.35
LMTD	14.38
Total Heat Transferred (BTU/hr)	82,310
Surface Effectiveness (Eta)	0.9254
Sensible Heat Transferred (BTU/hr)	82,310
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,159.45	36,020.13
Inlet Temperature (°F)	126.71	110.76
Outlet Temperature (°F)	123.48	112.86
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	125.10	111.81
Skin Temperature (°F)	115.46	113.45
Velocity ***	3,937.64	2.32
Reynold's Number	901**	15,577
Prandtl Number	0.7270	3.9644
Bulk Visc (lbm/ft·hr)	0.0478	1.4574
Skin Visc (lbm/ft·hr)		1.4340
Density (lbm/ft³)	0.0642	61.8342
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3672

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	809.07
j Factor	0.0072
Air-Side ho (BTU/hr·ft²·°F)	8.43
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.66
Effective Area (ft²)	1,009.35
LMTD	13.20
Total Heat Transferred (BTU/hr)	75,343
Surface Effectiveness (Eta)	0.9255
Sensible Heat Transferred (BTU/hr)	75,343
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,159.45	36,020.13
Inlet Temperature (°F)	123.48	108.84
Outlet Temperature (°F)	120.52	110.76
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	122.00	109.80
Skin Temperature (°F)	113.17	111.32
Velocity ***	3,937.64	2.32
Reynold's Number	905**	15,268
Prandtl Number	0.7273	4.0527
Bulk Visc (lbm/ft·hr)	0.0476	1.4870
Skin Visc (lbm/ft·hr)		1.4645
Density (lbm/ft³)	0.0645	61.8628
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3665

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	800.38
j Factor	0.0072
Air-Side ho (BTU/hr·ft²·°F)	8.41
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.64
Effective Area (ft²)	1,009.35
LMTD	12.12
Total Heat Transferred (BTU/hr)	68,993
Surface Effectiveness (Eta)	0.9257
Sensible Heat Transferred (BTU/hr)	68,993
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
VY03@104 F, 5%PLUG, 10%REDUCED

Extrapolation Calculation for Row 8(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	93,159.45	36,020.13
Inlet Temperature (°F)	120.52	107.09
Outlet Temperature (°F)	117.81	108.84
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	119.17	107.97
Skin Temperature (°F)	111.06	109.37
Velocity ***	3,937.64	2.32
Reynold's Number	908**	14,986
Prandtl Number	0.7275	4.1365
Bulk Visc (lbm/ft·hr)	0.0474	1.5149
Skin Visc (lbm/ft·hr)		1.4934
Density (lbm/ft³)	0.0648	61.8885
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3658

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	792.39
j Factor	0.0072
Air-Side ho (BTU/hr·ft²·°F)	8.40
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.63
Effective Area (ft²)	1,009.35
LMTD	11.12
Total Heat Transferred (BTU/hr)	63,202
Surface Effectiveness (Eta)	0.9258
Sensible Heat Transferred (BTU/hr)	63,202
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 9(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	93,159.45	36,020.13
Inlet Temperature (°F)	117.81	105.48
Outlet Temperature (°F)	115.32	107.09
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	116.57	106.28
Skin Temperature (°F)	109.13	107.58
Velocity ***	3,937.64	2.32
Reynold's Number	911**	14,730
Prandtl Number	0.7276	4.2156
Bulk Visc (lbm/ft·hr)	0.0473	1.5412
Skin Visc (lbm/ft·hr)		1.5208
Density (lbm/ft³)	0.0651	61.9116
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3652

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	785.06
j Factor	0.0072
Air-Side ho (BTU/hr·ft²·°F)	8.39
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	5.62
Effective Area (ft²)	1,009.35
LMTD	10.22
Total Heat Transferred (BTU/hr)	57,917
Surface Effectiveness (Eta)	0.9258
Sensible Heat Transferred (BTU/hr)	57,917
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

ComEd -- LaSalle

Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

VY03@104 F, 5%PLUG, 10%REDUCED

Extrapolation Calculation for Row 10(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	93,159.45	36,020.13
Inlet Temperature (°F)	115.32	104.00
Outlet Temperature (°F)	113.05	105.48
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	114.18	104.74
Skin Temperature (°F)	107.36	105.94
Velocity ***	3,937.64	2.32
Reynold's Number	914**	14,497
Prandtl Number	0.7278	4.2904
Bulk Visc (lbm/ft·hr)	0.0471	1.5660
Skin Visc (lbm/ft·hr)		1.5466
Density (lbm/ft^3)	0.0653	61.9325
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3646

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	778.32
j Factor	0.0072
Air-Side ho (BTU/hr·ft^2·°F)	8.38
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	5.61
Effective Area (ft^2)	1,009.35
LMTD	9.38
Total Heat Transferred (BTU/hr)	53,090
Surface Effectiveness (Eta)	0.9259
Sensible Heat Transferred (BTU/hr)	53,090
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2). Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Inlet Air Flowrate Calculator - 1(2)VY03A

Total P:	P=		14.315	psia	Inlet Air Flow
Dry Bulb T OUT:	T=		113.05	F	25210 acfm
Specific Hum.:	W =		0.020273629		
H2O Vap P:	Pv = (W*Rv*P)/(Ra+(W*Rv) =		0.451874527	psia	
		Rv =	85.778	(ft-lbf)/(lbm-R)	
		Ra =	53.352	(ft-lbf)/(lbm-R)	
Dry Air P:	Pa = P - Pv =		13.86312547	psia	
Dry Air rho OUT:	rho a = (144/Ra)*(Pa/(459.67+T) =		0.0653	lbm/ft^3	
Dry Air rho IN:	rho a = (144/Ra)*(Pa/(459.67+T) =		0.061575	lbm/ft^3	
Dry Bulb T IN:	T=		148	F	
Outlet Air Flow:	V =		23760	cfm	

CALCULATION TITLE PAGE PAGE NO. i

ComEd

LASALLE STATION

☒ Unit 1 ☒ Unit 2 ☐ Unit 0

CALCULATION NO: 97-199

DESCRIPTION CODE (C018): M03
DISCIPLINE CODE (C011): M
SYSTEM CODE (C011): VY
ELEVATION (C016):

TITLE: VY Cooler Thermal Performance Model – 1(2) VY03A

☒ Safety Related ☐ Regulatory Related ☐ Augmented Quality ☐ Non-Safety Related

REFERENCE NUMBERS: (C011 Panel)

Type	Number	Type	Number
AEDV			
CHRN			
PAL			
PROG			
PROJ			
YS			
NID			

COMPONENT EPN: (C014 Panel)

EPN	Component Type
1(2) VY03A	H15

DOCUMENT NUMBERS: (C012 Panel)

Doc Type	Sub Type	Document Number	Assoc. Calc.
CALC	ENG	L-002210	☒ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No
			☐ Yes ☐ No

REMARKS:

REV. NO.	REVISING ORGANIZATION	APPROVED (PRINT & SIGN)	DATE
B	C502	RICHARD HALL /	2/19/99

CALCULATION NO. 97-199 Project No: PAGE NO. ii

REVISION SUMMARIES

REV: B ☒ Partial (Only Revised Pages Included) ☐ Complete (All Calculation Pages Included)

REVISION SUMMARY:

Calculation revised to add additional sensitivity computer runs to assess effect of reduced inlet air flow rates on the total heat load transferred. pages i, ii, iii, iv, v, vi, vii, viii, ix, and Attachment P revised/added.
Attachment Q1 Added

Electronic Calculation Data Files:
(Program Name, Version, File name ext/size/date/hour/: min)
Electronic File Date for Rev. A of this Calculation is still valid, no new files are applicable.

Prepared by: Brian L. Davenport (Print) (Sign) 2-17-99 (Date)

Reviewed by: John Rommel (Print) (Sign) 2-19-99 (Date)

Type of Review: ☒ Detailed ☐ Alternate ☐ Test
Supplemental Review Required ☐ YES (NEP-12-05 documentation attached) ☑ NO
Supervisor

DO ANY ASSUMPTIONS IN THIS CALCULATION REQUIRE LATER VERIFICATION ☐ YES ☒ NO
Tracked by:

REV: ☐ Partial (Only Revised Pages Included) ☐ Complete (All Calculation Pages Included)

REVISION SUMMARY:

Electronic Calculation Data Files:
(Program Name, Version, File name ext/size/date/hour/: min)

Prepared by: (Print) (Sign) (Date)

Reviewed by: (Print) (Sign) (Date)

Type of Review: ☐ Detailed ☐ Alternate ☐ Test
Supplemental Review Required ☐ YES (NEP-12-05 documentation attached) ☐ NO
Supervisor

DO ANY ASSUMPTIONS IN THIS CALCULATION REQUIRE LATER VERIFICATION ☐ YES ☐ NO
Tracked by:

PROTO-POWER CORPORATION
CALCULATION TITLE SHEET

CLIENT: Commonwealth Edison

PROJECT: LaSalle Station GL 89-13 Heat Exchanger Testing Program

CALCULATION TITLE: VY Cooler Thermal Performance Model -- 1(2)VY03A

CALCULATION NO.: 97-199

FILE NO.: 31-003

COMPUTER CODE & VERSION (if applicable): PROTO-HX™, Version 3.01

REV	TOTAL NO. OF PAGES	ORIGINATOR/DATE	VERIFIER/DATE	APPROVAL/DATE
A	203	Lloyd Philpot JE Philpot 7/7/98	Merid Aboye 7/7/98	7-8-98

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iv of ix | 2/19/99

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	VERIFIED BY M. Aboye		JOB NO. 31-003
CLIENT Commonwealth Edison	PROJECT LaSalle Station GL 89-13 Heat Exchanger Testing		
TITLE VY Cooler Thermal Performance Model -- 1(2)VY03A			

Revision History

Revision	Revision Description
A	Original Issue

PROTO-POWER CORPORATION **GROTON, CONNECTICUT**	CALC NO. 97-199	REV A	PAGE ~~iii OF vi~~ v OF ix DZD 2/19/99
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	VERIFIED BY M. Aboye		JOB NO. 31-003
CLIENT Commonwealth Edison	PROJECT LaSalle Station GL 89-13 Heat Exchanger Testing		
TITLE VY Cooler Thermal Performance Model -- 1(2)VY03A			

CALCULATION VERIFICATION FORM

REVIEW METHOD:			EXTENT OF VERIFICATION:	
Approach Checked:	☑	N/A ☐	Complete Calculation:	☑
Logic Checked:	☑	N/A ☐		
Arithmetic Checked:	☑	N/A ☐	Revised areas only:	☐
Alternate Method (Attach Brief Summary)	☐	N/A ☑		
Computer Program Used (Attach Listing)	☐	N/A ☑	Other (describe below):	☐
Other	☐	N/A ☑		

*Errors Detected

NONE

*Error Resolution

*Other Comments

NONE

*Extra References Used

*(Attach extra sheets if needed)

CALCULATION FOUND TO BE VALID AND CONCLUSIONS TO BE CORRECT AND REASONABLE:

IDV Signature:

Initials: MA

Printed Name: MERID ABOYE

Date: 7-7-98

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TITLE VY Cooler Thermal Performance Model -- 1(2)VY03A			

Total Number of Pages in Body of Calculation: 24

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TITLE VY Cooler Thermal Performance Model -- 1(2)VY03A			

LIST OF ATTACHMENTS

Attachment	Subject Matter	Total Pages
A	Attachment A to Proto-Power Calculation 97-199 Rev. A: Design Input Data -- Selected References	11
B	Attachment B to Proto-Power Calculation 97-199 Rev. A: Cooler Inspection Photographs -- 1VY03A	2
C	Attachment C to Proto-Power Calculation 97-199 Rev. A: PROTO-HX™ Reports -- Initial Benchmark Case	9
D	Attachment D to Proto-Power Calculation 97-199 Rev. A: Excerpt from *Compact Heat Exchangers*, Kays and London	2
E	Attachment E to Proto-Power Calculation 97-199 Rev. A: PROTO-HX™ Reports -- Final Benchmark Case	17
F	Attachment F to Proto-Power Calculation 97-199 Rev. A: PROTO-HX™ Reports -- Thermal Margin Assessment (Clean)	9
G	Attachment G to Proto-Power Calculation 97-199 Rev. A: PROTO-HX™ Reports -- Thermal Margin Assessment (Service)	9
H	Attachment H to Proto-Power Calculation 97-199 Rev. A: Derivation of Moist Air Properties	18
I	Attachment I to Proto-Power Calculation 97-199 Rev. A: PROTO-HX™ Reports -- Limiting Flow Analysis	25
J	Attachment J to Proto-Power Calculation 97-199 Rev. A: PROTO-HX™ Analytical Uncertainty Analysis	43
K	Attachment K to Proto-Power Calculation 97-199 Rev. A: Comparing Surface Areas of Spiral and Circular Fins	4
L	Attachment L to Proto-Power Calculation 97-199 Rev. A: Walkdown Data for Coil Physical Dimensions	5
M	Attachment M to Proto-Power Calculation 97-199 Rev. A: PROTO-HX™ Reports -- Fouling Sensitivity Analysis	17
N	Attachment N to Proto-Power Calculation 97-199 Rev. A: PROTO-HX™ Model Database Disk	2 (plus disk)

~~Complete Calculation (total number of pages): 203~~ 2/21/99

List of Attachments (cont.)

Project No:

CALCULATION NO. 97-199	REV. NO. B	PAGE NO. ix of ix
ATTACHMENTS	SUBJECT MATTER	TOTAL PAGES
O	Attachment O. (not used)	P1 - P1 ~~N/A~~ 2/21/99
P	Attachment P, to Calculation 97-199, Rev. B, Sensitivity Computer Runs for Reduced Inlet Air Flow Rates	28 P1 - P28 2/21/99

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CLIENT Commonwealth Edison	PROJECT LaSalle Station GL 89-13 Heat Exchanger Testing		
TITLE VY Cooler Thermal Performance Model -- 1(2)VY03A			

1. PURPOSE

The purpose of this calculation is to develop a thermal performance analysis model for the Commonwealth Edison (ComEd) LaSalle Station SE cubicle area coolers 1(2)VY03A. This model can be used for the analysis of heat exchanger thermal performance test data as part of the LaSalle Station GL 89-13 heat exchanger testing program or for any other engineering analysis subject to the limitations itemized at the end of this section.

Once developed, the model is used to identify the thermal margin of the heat exchanger at specified performance conditions as follows:

- at LaSalle Station Reference Conditions as currently defined in the LaSalle Station design and licensing basis; and
- at lower service water flow rates (with increased fouling) to support service water system re-balancing efforts.

The thermal performance model documented in this calculation has been created and used with PROTO-HX, Version 3.01. The model can be used with previous versions of PROTO-HX and produce identical results as long as the following restriction is upheld:

- Air coils analyzed in Version 3.0 or earlier can be analyzed only in non-condensing modes of operation.

Current limitations of use for PROTO-HX are established by the limits on fluid properties included within the software. Fluid properties contained within PROTO-HX are currently limited to the following temperature ranges:

• Air:	32-320°F
• Water:	32-500°F

2. BACKGROUND

LaSalle Station is in the process of implementing a heat exchanger thermal performance monitoring program and a service water system flow balancing program in response to the requirements of NRC Generic Letter 89-13. Development of an analytical model in PROTO-HX™, Version 3.01, will allow timely analysis of data resulting from the test program and will ensure the limiting flow requirements for the coolers are adequately defined.

3. DESIGN INPUTS

The thermal performance model is developed using PROTO-HX™, Version 3.01. PROTO-HX™ was developed and validated in accordance with Proto-Power's Nuclear Software Quality Assurance Program (SQAP). This program meets the requirements of 10CFR50 Appendix B, 10CFR21, and ANSI NQA-1, and was developed in accordance with the guidelines and standards contained in ANSI/IEEE Standard 730/1984 and ANSI NQA-2b-1991. PROTO-HX™ Version 3.01 was verified and approved for use as documented in Reference (1).

The design inputs for this calculation consist of the heat exchanger design basis performance requirements (Table1), performance specifications (Table 2) and construction details (Table 3) provided by the heat exchanger manufacturer data sheet (Attachment A) or other design documents as referenced. Construction details give the necessary information for model construction while performance specifications are used to benchmark the model.

VY cooler thermal performance in this calculation will be assessed only with respect to the nominal accident conditions (i.e., design basis LOCA) with no tubes plugged. Condensing modes of operation and tube plugging margins are not addressed.

Table 1: LaSalle Station Reference Conditions

Parameter	Value	Reference*
Heat Rate -- 1(2)VY013A (BTU/hr)	722,217	2
Atmospheric Pressure (in-w.g.)	-0.4	4
Air-Side Inlet Temperature -- Dry Bulb (°F)	148	4
Fan Volumetric Flow Rate (cfm)	26,400	18,19
Tube-Side Flow Rate (gpm)	180	5
Tube-Side Inlet Temperature (°F)	100	6

*Selected references included as Attachment A

PROTO-POWER CORPORATION GROTON, CONNECTICUT	CALC NO. 97-199	REV A	PAGE 3 OF 24
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	VERIFIED BY M. Aboye		JOB NO. 31-003
CLIENT Commonwealth Edison	PROJECT LaSalle Station GL 89-13 Heat Exchanger Testing		
TITLE VY Cooler Thermal Performance Model -- 1(2)VY03A			

Table 2: Vendor Specified Performance

Parameter	Value	Reference*
Air-Side Fouling Factor (Design)	0	Assumption (1)
Air-Side Entering Fluid Flow Rate (scfm)	25,420	7
Air-Side Inlet Dry Bulb Temperature (°F)	150	7
Air-Side Inlet Wet Bulb Temperature (°F)	92	7
Air-Side Outlet Dry Bulb Temperature (°F)	108.8	7
Air-Side Outlet Wet Bulb Temperature (°F)	84.0	7
Tube Side Fouling Factor (Design)	0.0015	8
Tube Side Fluid Type	Service Water (Fresh)	9,10
Tube Side Fluid Flow Rate, Total (gpm)	180	7
Tube Side Inlet Temperature (°F)	105	7
Tube Side Outlet Temperature (°F)	117.7	7
Design Q (BTU/hr)	1,108,000	7

*Selected references included as Attachment A

Table 3: Construction Details

Parameter	**Value**	**Reference(1)**
Heat Exchanger Type and relative direction of Tube-side and Air flow .	Carrier Air Coil Counter flow	7,11
Fin Type	Spiral	7,8
Coil Finned Length (in)	111.00 -- specified (2) 108.00 -- effective (2) (4)	7 20
Fin Pitch (fins/in)	10.0	7
Fin Material	ASTM B209 Aluminum	7
Fin Conductivity (BTU/hr-ft-°F)	128	16
Fin Thickness (in)	0.012	7
Fin Height (in)	1.452	20
Number of Coils per Unit	2	7
Number of Tube Rows	10	7
Number of Tubes per Row	24	7
Number of Plugged Tubes	0	-
Tube Outside Diameter (in)	0.625 (3)	7
Tube Wall Thickness (in)	0.049	7
Tube Inside Diameter (in)	0.527	7
Longitudinal (horizontal) Tube Pitch (in)	Unavailable - see Section 6	-
Transverse (vertical) Tube Pitch (in)	1.410	20
Tube Layout	Staggered	20
Number of Serpentines	1 (i.e., "Full Circuiting")	7
Tube Wall Material	SB75 Copper	7
Tube Wall Conductivity (BTU/hr-ft-°F)	225	12
Sensible Heat Ratio	1	(Section 6.3)

Notes:
(1) Selected references included as Attachment A
(2) The Reference (7) coil finned length will be used for benchmarking to vendor performance data per Section 6.0. The Reference (20) effective coil finned length will be used for all subsequent analyses.
(3) The Reference (7) tube OD is within the tolerance of Reference (20) and will be used in lieu of the Reference (20) value.
(4) Two tubes in the first row of 1VY03A are missing fins over a tube length of 5 1/4" per Reference (3) (addressed in Section 6.10).

4. APPROACH

This calculation utilizes plant/vendor fabrication specifications provided in Section 3.0 to develop a thermal performance prediction model for the 1(2)VY03A cooler. The calculation then benchmarks the model by comparing the heat transfer rate calculated by PROTO-HX™ Version 3.01 with the manufacturer's specifications for thermal performance. The Colburn j-factor vs. Reynolds Number relationship is adjusted as necessary to meet the manufacturer's performance specifications. After the model is benchmarked, it will be used to determine the margin between the available and required heat removal rates and to establish a revised limiting flow rate in support of service water system re-balancing efforts.

5. ASSUMPTIONS

1. The fouling factor specified in Reference (8) is for the tube-side only and design air-side fouling is zero. This is typical for air coils of this type and application. Future validation of this assumption is not required.

2. The slope of the "Colburn j-factor vs. Reynolds Number" curve is the same for the current coil and the standard coil represented by curve "CF-9.05-3/4 J-A" in the PROTO-HX™ "h-configurations" Library. This assumption is based on physical similarities between the VY coolers and the standard configuration represented by "CF-9.05-3/4 J-A" as elaborated in Section 6, below. The model benchmarking process described in Section 6 brings the model into precise agreement with the vendor performance data making initial configuration selection immaterial. The only difference caused by initial configuration selection that would be detectable in analysis results is when analyses are performed over a very wide range (orders of magnitude) of air-side Reynolds numbers. A wide range of Reynolds numbers causes the slight variation in slopes of the j-factor equations of different configurations to become more obvious. Given the fixed fan flow rate and a relatively tight band of normal operating and Reference conditions, along with the fact that benchmarking conditions are extremely close to Reference conditions, such wide variations in Reynolds numbers are not anticipated. Future validation of this assumption is not required.

3. The vendor-supplied performance specifications of Reference (7) (included as Attachment A) are considered to be an accurate reflection of the as-built performance of the cooler. Future validation of this assumption is not required.

4. The VY cooler spiral fin geometry is closely approximated by the PROTO-HX™ circular fin configuration. This is due to the relatively tight fin pitch configuration resulting in a

negligible difference in fin/tube outside surface area. This assumption is supported in Attachment K. Future validation of this assumption is not required.

5. In transitioning from the original vendor specified inlet air temperature of 150°F to the current licensing limit of 148°F, the inlet air vapor density is assumed to have remained unchanged. This increases the inlet relative humidity causing a slight reduction in the air mass flow rate. Future validation of this assumption is not required.

6. ANALYSIS

6.1 Tube Pitch

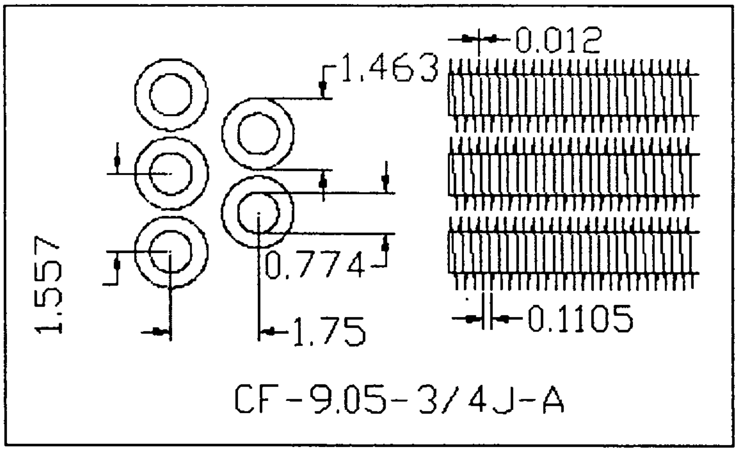
The longitudinal (horizontal) tube pitch is not directly available from the coil data sheet or Reference (20). It can be estimated based on the geometry of the coil. Per Reference (7), the coil stack depth is 14.00 inches. Dividing the stack depth evenly between 10 tube rows yields a longitudinal (horizontal) tube pitch of 1.400 inches.

6.2 Coil Configuration

The coil configuration for modeling cooler 1(2)VY03A is selected based on the physical characteristics of the coil. There are no coils in the PROTO-HX™ library that exactly match the configuration of cooler 1(2)VY03A. The configuration "CF-9.05-3/4 J-A" shown in Figure 1 provides the closest match based on similarities of layout geometry: staggered tube rows, identical fin thickness, similar fin height and similar fin pitch. The "CF-9.05-3/4 J-A" configuration also represents a relatively compact coil which correlates well to the VY coils as evidenced in the coil photographs included as Attachment B.

PROTO-HX™ does not include spiral fin configurations in the analytical methodology employed. However, for the given fin pitch, the difference in calculated fin surface area between the VY cooler spiral fin configuration and the PROTO-HX™ circular fin configuration is negligible. The negligible difference is illustrated further in Attachment K using a simplified area comparison.

Figure 1 Coil Configuration CF-9.05-3/4 J-A



6.3 Sensible Heat Ratio

The Sensible Heat Ratio (SHR) is used only when one of the "Constant Heat Load" calculation and/or extrapolation methods of PROTO-HX™ is used (i.e., "Constant Heat and Cold Inlet Temperature" or "Constant Heat and Hot Outlet Temperature"). The SHR can be assigned any value between 0 and 1 and represents the fraction of the total specified (constant) heat load that is due to sensible cooling alone. An input of 1.0 in the SHR field tells PROTO-HX™ that the specified constant heat is 100% sensible heat with no condensation occurring. Use of any value less than 1.0 presumes some knowledge as to what fraction of the specified heat load is due to condensation (i.e., latent heat transfer). The value of SHR currently in the model is 1.0, but like any other model input, the SHR can be changed at any time.

6.4 Derivation of Benchmarking Inputs

The PROTO-HX™ model is benchmarked using the performance data provided by the cooler manufacturer. In order to benchmark the model, the vendor specified conditions must be converted into appropriate units for PROTO-HX™ input. The only input requiring adjustment is the specified air-side flow rate of 25,420 *scfm*. PROTO-HX™ requires air-side flow rate to be given at actual inlet air conditions (units of *acfm*).

The correction of *scfm* to *acfm* is made as follows (holding mass flow rate constant for the defining case):

$$\dot{m} \;=\; (\text{scfm}) \text{ x } (\rho_{\text{std}}) \text{ x } \left(\frac{60\,\text{min}}{1\,\text{hr}}\right) \;=\; (\text{acfm}) \text{ x } (\rho_{\text{actual}}) \text{ x } \left(\frac{60\,\text{min}}{1\,\text{hr}}\right) \qquad \text{Equation (1)}$$

where:

$\dot{m}$ = mass flow (lbm/hr)

scfm = volumetric flow rate at standard conditions (ft^3/min)

ρ_{std} = standard density of 0.075 lbm/ft^3

acfm = volumetric flow rate at specified (non-standard) conditions (ft^3/min)

ρ_{actual} = density of dry air at specified inlet temperature and humidity (lbm/ft^3)

Rearranging terms yields the following correction factor for converting scfm to inlet acfm:

$$(\text{acfm}) \;=\; (\text{scfm}) \text{ x } \frac{(\rho_{\text{std}})}{(\rho_{\text{actual}})} \qquad \text{Equation (2)}$$

Local Standard Atmospheric Pressure

To derive the dry air density for the inlet air conditions, the amount of moisture in the air and the local atmospheric pressure must be accounted for. Per Reference (13), local atmospheric pressure was accounted for by specifying a flow at standard density (25,420 scfm) as well as an actual flow (26,400 acfm at 70°F and 40% relative humidity at site elevation). The difference between the two flow rates will provide the assumed air density as follows:

$$(\rho_{\text{actual}}) \;=\; (\text{scfm}) \text{ x } \frac{(\rho_{\text{std}})}{(\text{acfm})} \;=\; (25{,}420) \;\text{ x }\; \frac{0.07500}{26{,}400} \;=\; 0.0722 \;\; {}^{\text{lbm}}\!/\!_{\text{ft}^3}$$

The local atmospheric pressure is found by iterative solution using Reference (14) as shown in Attachment H. Pressure input is varied with the specified temperature and humidity conditions held constant until a dry air density of 0.0722 lbm/ft^3 is reached.

The result of the iterative process is as follows:

Given per Reference (13)
Dry Bulb Temperature: 70.00°F
Relative Humidity: 40.00 %

Derived above
Dry Air Density: 0.07220 lbm/ft^3

Derived per Attachment H
Specific Humidity: 0.00638 lbmv/lbma
Atmospheric Pressure: **14.3150 psia**
Dry Air Pressure: 14.1697 psia
Vapor Pressure: 0.1453 psia
Vapor Density: 0.00046 lbm/ft^3

The result is that an atmospheric pressure of 14.315 psia at 70°F and 40% relative humidity will give the requisite air density.

Actual Air Flow Rate

The next step is to define the actual air flow rate at the inlet conditions included by the vendor in the Reference (7) performance specification (Table 2). The moist air conditions corresponding to the vendor specified performance conditions are as follows:

Given per Reference (7)
Dry Bulb Temperature: 150.00°F
Wet Bulb Temperature: 92.00°F

Derived above
Atmospheric Pressure: 14.315 psia

Derived per Attachment H
Relative Humidity: 12.18 %
Specific Humidity: 0.02034 lbmv/lbma
Dry Air Pressure: 13.8617 psia
Vapor Pressure: 0.4533 psia
Dry Air Density: **0.06137 lbm/ft^3**
Vapor Density: 0.001248 lbm/ft^3

The actual volumetric flow rate at vendor specified inlet conditions is then calculated as:

$$(\text{acfm}) = (\text{scfm}) \times \frac{(\rho_{\text{std}})}{(\rho_{\text{actual}})} = (25{,}420) \times \frac{0.07500}{0.06137} = 31{,}066 \ {}^{\text{ft}^3}\!/_{\text{min}}$$

Summary of PROTO-HX™ Inputs for Model Benchmarking

Tube-Side Flow Rate	180 gpm
Tube-Side Inlet Temperature	105°F
Air-Side Flow Rate	31,066 acfm
Air-Side Inlet Temperature -- Dry Bulb	150°F
Air-Side Inlet Temperature -- Wet Bulb	92°F
Atmospheric Pressure	14.315 psia

6.5 Model Benchmarking

Model benchmarking is performed to compare thermal performance as predicted by the model to thermal performance specified by the cooler vendor. A significant impact on the model predicted performance is the outside (air-side) heat transfer coefficient. The benchmarking process adjusts the model correlation for outside heat transfer coefficient to match vendor performance data.

An extensive source of information pertaining to the outside heat transfer coefficient for air coolers is provided by Reference (15). This widely-recognized publication provides heat transfer correlations for specific coil configurations. The format used in Reference (15), and subsequently adopted by other researchers, is to provide a plot of the Colburn j-factor vs. Reynolds Number for each configuration.

Alternatively, to permit modeling of coils which do not adequately fit the library configurations and for which no test data correlation is available, PROTO-HX™ allows the generation of a coil unique formulation for outside heat transfer coefficient. This is done through establishing a unique Colburn j-factor for the coil.

Reference (15) defines the Colburn j-factor as follows.

Let:

c_{pa} = Specific heat of air (Btu/lb$_m$-°F)

k_a = Thermal conductivity of air (Btu/hr-ft-°F)

m_a = Absolute viscosity of air (lb_m/ft-hr)

r_a = Density of air (lb_m/ft^3)

A_{min} = Minimum air-side flow area (in^2)

A_I = Frontal Area (in^2)

D_H = Hydraulic diameter (ft)

d_O = Tube outside diameter (in)

j = Colburn j-Factor

N_C = Number of coils per unit

N_L = Number of active tube rows

Q_a = Specified air flow rate (acfm)

S_L = Longitudinal Tube Pitch (in)

S_T = Transverse Tube Pitch (in)

The Prandtl Number for air, Pr_a (a dimensionless parameter), is given by:

$$Pr_a = \frac{c_{pa}\ \mu_a}{k_a}$$ Equation (3)

The mass flow rate of air per coil, M_a (lb_m/hr), is calculated based on the input total air flow and the number of coils per unit:

$$M_a = \frac{60\,\rho_a Q_a}{N_C}$$ Equation (4)

The bulk-stream mass flux, G (lb_m/ hr-ft^2), is:

$$G = \frac{144\ M_a}{A_{MIN}} \qquad \text{Equation (5)}$$

The Colburn j-factor is defined in terms of the Stanton Number, St_a, as:

$$j = St_a\ Pr_a^{2/3} = \left(\frac{h_o}{G\ c_{pa}}\right) Pr_a^{2/3} \qquad \text{Equation (6)}$$

Therefore, the outside heat transfer coefficient, h_o (Btu/hr-ft^2-°F), may be defined in terms of the j-factor:

$$h_o = \frac{j\ G\ c_{pa}}{Pr_a^{2/3}} \qquad \text{Equation (7)}$$

Per Reference (15), the j-factor for the various coil configurations tested are provided as functions of the Reynolds Number based on hydraulic diameter, D_H(in):

$$j = f(Re_a) \qquad where:\ Re_a = \frac{G\ D_H}{\mu_a} \qquad \text{Equation (8)}$$

The standard air-side configuration for coil type CF-9.05-3/4 J-A, provided in PROTO-HX™ 's Library, was initially selected based on the physical similarities between the present coil and that represented by CF-9.05-3/4 J-A as described in Section 6.2. However, the heat transfer rate under design operating conditions using the standard configuration was slightly greater than the value specified by the manufacturer (see performance run in Attachment C). For this reason, a new curve relating the Colburn j-factor and Reynolds Number was generated according to the following procedure:

- The slope of the linear standard curve was calculated.
- A new curve, parallel to the standard curve, was defined such that the new j-intercept is slightly lower.

- A design performance run was then executed using the new Colburn j-factor versus Reynolds Number curve, and the resulting heat transfer rate was compared to the manufacturer's value.

- The above two steps were repeated until the calculated heat transfer rate closely matched the manufacturer's value.

The resulting relationship between Reynolds Number and Colburn j-Factor is represented by the following table and associated equation:

Table 4: Reynolds Number and Colburn j-Factor

Reynolds Number	Colburn j-Factor (Standard)	Colburn j-Factor (Custom)
1000	0.009	0.00695
8000	0.0044	0.00340

$$j = e^{\left[-2.5939\ -\ 0.3438 * \mathrm{Ln}(\mathrm{Re})\right]} \qquad \text{Equation (9)}$$

Equation (9) was added to the PROTO-HX™ Library for use in conjunction with Area Coolers 1(2)VY03A.

As noted in Assumption (2) and implemented above, the slope of the "Colburn j-factor vs. Reynolds Number" curve is assumed to be the same for cooler 1(2)VY03A and the standard coil represented by curve CF-9.05-3/4 J-A in the PROTO-HX™ "h-configurations" Library. This assumption is considered reasonable based on the following:

- there are only minor variations in the slope of different j-factor correlations; and,

- there is only a slight variation in the air-side Reynolds Number between anticipated test conditions and the extrapolated accident conditions. The only variation is expected to be caused by air inlet temperature variations (i.e., volumetric flow rate in cfm will be nearly constant, while air flow in acfm will vary with temperature and inlet humidity).

An excerpt from Reference (15), illustrating the j-factor relationship with Reynolds number, is included as Attachment D.

6.6 Effective Coil Finned Length

Reference (20) identified the fact that the fined coil length exposed to air flow was less than that specified by the coil vendor in Reference (7). Model benchmarking used the vendor specified length to be consistent with the vendor specified performance. The effective length is entered into the model after benchmarking to be used for all subsequent analysis. An effective coil finned length of 108.00 inches is used per Reference (20).

6.7 Extrapolation Conditions

The LaSalle Station Reference Conditions defined in Table 1 are slightly different than the vendor specified performance conditions listed in Table 2 and require conversion to units for input into PROTO-HX™.

Air-Side Pressure

Air-side pressure should account for the local elevation above sea level. Chapter 26, Table 1A, of Reference (16) provides elevation and standard atmospheric pressure data for the local area around La Salle.

Interpolating between data points to derive the pressure associated with the elevation of the VY coolers given by Reference (17) provides the following:

Elevation (feet above sea level)	**Pressure (psia)**	
682	14.337	Reference (16)
738	14.308	Reference (16)
698	14.329	Interpolation between above points at VY elevation

Per Reference (4), the coil pressure is -0.4 inches of water gauge. Using the density of water at 60°F, the specified pressure is calculated as illustrated below:

Coil Pressure (inwg)	**Water Density (lbm/ft$^{3)}$**	**Coil Pressure (psig)**	**Atm Pressure (psia)**	**Coil Pressure (psia)**
-0.4	62.36445	-0.014	14.329	14.315

This pressure matches the pressure derived from the original coil specification in Section 6.4.

Air-Side Flow Rate

In order for PROTO-HX™ to calculate the air mass flow rate for a given extrapolation condition, the inlet dry bulb temperature, total pressure, and relative humidity or wet bulb temperature must be specified. The inlet dry bulb temperature and pressure for the LaSalle Station Reference Conditions are listed in Table 1. The inlet relative humidity is adjusted by holding the vapor density constant from the vendor specified condition to the LaSalle Station Reference Condition (i.e., 148°F in lieu of 150°F).

Given per Section 6.4
Vapor Density: 0.001248 lbm/ft^3

Reference Condition
Dry Bulb Temperature: 148.00°F
Atmospheric Pressure: 14.315 psia

Derived per Attachment H
Wet Bulb Temperature: 91.6°F
Relative Humidity: **12.76 %**

Since fans are constant volume equipment, the air volumetric flow rate of 26,400 cfm specified in References (18) and (19) remains the same for all coil outlet conditions. The air mass flow rate through the coil, however, will vary with the temperature of the air going through the fan (i.e., at coil outlet temperature). Deriving the inlet air flow rate for input to PROTO-HX™ requires an iterative solution as follows:

- take an initial guess at the coil outlet air temperature at the same specific humidity as the coil inlet;
- calculate the dry air density at the selected coil outlet air temperature;
- calculate the coil inlet air flow rate by multiplying the fan capacity (cfm) by the ratio of the coil outlet dry air density to the coil inlet dry air density (to maintain constant mass flow across the coil) [Equation (2)];
- run the model with the inlet air flow rate derived above;
- check the predicted coil outlet air temperature; and
- repeat the process (substituting the predicted coil outlet air temperature for the initial guess) until the coil outlet air temperature does not change from one iteration to the next

The iteration process described above was completed twice for this model for a clean (f = 0.0) and service (f = design) condition with results as follows:

Clean:

$$(\text{cfm}_{\text{in}}) = (\text{cfm}_{\text{out}}) \text{ x } \frac{(\rho_{\text{out}})}{(\rho_{\text{in}})} = (26{,}400) \text{ x } \frac{(0.066345159)}{(0.061575103)} = 28{,}445 \text{ (Fan Temperature = 104.31)}$$

Service:

$$(\text{cfm}_{\text{in}}) = (\text{cfm}_{\text{out}}) \text{ x } \frac{(\rho_{\text{out}})}{(\rho_{\text{in}})} = (26{,}400) \text{ x } \frac{(0.066128241)}{(0.061575103)} = 28{,}352 \text{ (Fan Temperature = 106.16)}$$

Summary of PROTO-HX™ Inputs for Extrapolation to Reference Conditions

The Extrapolation conditions are defined as the vendor data sheet conditions without high energy line break modified for ultimate heat sink temperature and room limiting temperature per the LaSalle Station UFSAR Reference (4).

The required PROTO-HX™ inputs for these conditions are as follows:

Tube-Side Flow Rate	180 gpm
Tube-Side Inlet Temperature	100°F
Air-Side Flow Rate	(varies with temperature)
Air-Side Inlet Temperature -- Dry Bulb	148°F
Air-Side Inlet Humidity	12.76%
Atmospheric Pressure	14.315 psia

6.8 Thermal Margin Assessment

The available thermal margin is defined as the difference between the available and the required heat removal rates at reference conditions. The maximum available heat removal rate is calculated using the benchmarked PROTO-HX™ model and the inlet conditions defined in Section 6.7 with zero fouling. By comparing the available heat removal rate calculated with zero fouling (q_{clean}) to the required heat removal rate, the maximum available margin is determined. A similar comparison is made between the required heat load to the available heat load at design fouling conditions (q_{service}).

For the purposes of this thermal margin assessment, thermal margin is defined as follows:

$$\text{Margin (BTU / hr)} = q_{\text{available}} - q_{\text{required}} \qquad \text{Equation (10)}$$

$$\text{Margin (\%)} = \left(\frac{q_{\text{available}} - q_{\text{required}}}{q_{\text{required}}} \right) \times 100 \qquad \text{Equation (11)}$$

where:

$q_{\text{available}}$ = the predicted heat capacity of the cooler at the specified conditions (BTU/hr)

q_{required} = the heat capacity required of the cooler to fulfill design basis requirements (BTU/hr)

6.9 Limiting Cooling Water Flow Analysis

In support of the LaSalle Station efforts to re-balance the CSCS Equipment Cooling Water System, specification of a minimum acceptable cooling water flow to the VY coolers is desired. For conservatism, the design fouling factors associated with the limiting flow analysis are increased to 0.002 on both the tube and air sides of the cooler. Increasing the design fouling factors increases the fouling margin of the cooler at the reduced flow rates.

Limiting flows are established by iterating with the performance model. The cooling water flow rate is incrementally reduced with each iteration until the target thermal margin of approximately 30% with the increased design fouling factors is achieved.

6.10 Impact of Missing Fins

Reference (3) identified the fact that two of the tubes in the front row of 1VY03A are missing fins for a tube length of 5.25 inches leaving an adjusted finned tube length of 102.75 inches. This reduces the heat transfer surface area for the first row. To assess the impact of this configuration, an additional iteration is made with the model. Since PROTO-HX™ does not allow the specification of different lengths by tube row, a comparison of the thermal performance capability of a coil with proper finned length to that of a coil with the adjusted finned length is required. This is done by running the model with a revised value for coil finned length. The results of the PROTO-HX™ analysis of this configuration is then compared to the results with the effective coil finned length defined in Section 6.6. By focusing only on the heat transfer results tabulated for the first row, a difference in thermal performance attributable to the shorter coil finned length can be identified. By pro-rating the differences identified to account for the fact that only 2 of the 24 tubes in the first row are affected, an estimation of the net effect is obtained.

6.11 Fouling Sensitivity Analysis

To assess the sensitivity of the 1(2)VY03A coolers to tube-side fouling accumulations, a series of iterations are performed. With each iteration, the design tube-side fouling factor is incrementally increased from a value of 0.0000 to 0.0040 while the air-side fouling factor is held constant at the revised level of 0.002. The heat removal capability resulting from each fouling increment is compared to the required heat load to assess the thermal margin. Thermal margin is calculated using Equations (10) and (11).

7. RESULTS

7.1 Model Benchmarking

The first model case was based on the standard CF-9.05-3/4 J-A configuration available from the PROTO-HX™ library. The results of this initial benchmarking case are presented in Table 5. The PROTO-HX™ reports associated with the initial benchmark case are included as Attachment C.

Table 5: Initial Benchmark Case -- Standard CF-9.05-3/4 J-A Configuration

Cooler	Design q(1) (BTU/hr)	PROTO-HX™ Predicted q (BTU/hr)	Percent Difference
1(2)VY03A	1,108,000	1,157,626	+ 4.48%

(1) Heat rate specified by cooler vendor

Based on the results of the initial benchmark case with the standard CF-9.05-3/4 J-A configuration, another case was completed using a customized Colburn J-Factor. This case demonstrated adequate benchmarking of the model to the vendor specified performance. A subsequent comparison run was made following the adjustment of the coil finned length to match the length identified in Reference 20. The results of the final benchmarking cases are presented in Tables 6 and 7. The PROTO-HX™ reports associated with the final benchmarking cases are included as Attachment E.

Table 6: Final Benchmark Case -- Customized Colburn J-Factor

Cooler	Design q (BTU/hr) $^{(1)}$	PROTO-HX™ Predicted q (BTU/hr)(2)	Percent Difference
1(2)VY03A	1,108,000	1,108,052	+ 0.0047%

(1) Heat rate specified by cooler vendor
(2) With specified coil finned length per Reference 7 (benchmarking basis)

Table 7: Final Benchmark Case -- Effective Coil Finned Length

Cooler	Design q (BTU/hr) $^{(1)}$	PROTO-HX™ Predicted q (BTU/hr)(2)	Percent Difference
1(2)VY03A	1,108,000	1,103,074	- 0.44%

(1) Heat rate specified by cooler vendor
(2) With effective coil finned length per Reference 20 (subsequent analysis basis)

7.2 Cooler Thermal Margin Results

Prior to defining margin, the predicted heat transfer capacity of the cooler ($q_{available}$) is defined. The predicted heat transfer capacities at LaSalle Station Reference Conditions for both clean (zero fouling) and service (design fouling) conditions are summarized in Table 8.

Table 8: Heat Transfer Capacity

Conditions	Heat Transfer Capacity (BTU/hr)
Nominal (dry) -- clean (f = 0.0000)	1,148,793
Nominal (dry) -- service (f = 0.0015)	1,096,666

The thermal margin assessment relates the predicted capacity of the cooler at clean and service conditions to the required capacity under reference conditions. The comparison is provided in Table 9. The PROTO-HX™ reports associated with the thermal margin assessment are included as Attachments F and G for zero and design fouling conditions, respectively.

Table 9: Thermal Margin at LaSalle Station Reference Conditions

Cooler	Fouling	$q_{required}$ (BTU/hr)	$q_{available}$ (BTU/hr)	Margin (BTU/hr)	Margin (%)
1(2)VY03A	zero (clean)	722,217	1,148,793	426,576	59.06%
1(2)VY03A	design (service)	722,217	1,096,666	374,449	51.85%

7.3 Limiting Cooling Water Flow Rate Analysis

The limiting cooling water flow analysis calculated the lowest possible cooling water flow that would provide a thermal margin of approximately 30% for the 1(2)VY03A coolers. The results of the iterations to identify the limiting flow rate are summarized in Table 10. The PROTO-HX™ reports associated with the limiting flow analysis are included as Attachment I.

Table 10: Limiting Cooling Water Flow Rate at LaSalle Station Reference Conditions

Cooler	Limiting Flow Rate	$q_{required}$ (BTU/hr)	$q_{available}$ (BTU/hr)	Margin (BTU/hr)	Margin (%)
1(2)VY03A	72.5 gpm	722,217	938,124	215,907	29.90%

The uncertainty in the analytical methodology used to identify the limiting flow for 1(2)VY03A is presented in Attachment J. The result of the uncertainty assessment is that the uncertainty in the PROTO-HX™ extrapolated heat transfer rate ranges from ± 3.71 to ± 4.09% for the ranges of cooling water flow evaluated. An uncertainty of ± 4.50% is used to conservatively bound the analysis of Attachment J. The adjusted thermal margin is calculated using Equation (11) after subtracting the uncertainty from the available heat rate. The results are presented in Table 11 below.

Table 11: Limiting Cooling Water Flow Rate at LaSalle Station Reference Conditions

Cooler	Limiting Flow Rate	$q_{required}$ (BTU/hr)	$q_{available}$ (BTU/hr)	Margin (BTU/hr)	Margin (%)
1(2)VY03A	72.5 gpm	722,217	895,908	173,691	24.05%

7.4 Impact of Missing Fins

The assessment of the impact of missing fins in 1VY03A was made at the limiting flow condition defined in the previous section (i.e., at 72.5 gpm). The results of the analysis are as follows:

1VY03A Row #1 with nominal length of 108.00" at 72.5 gpm:	123,422 BTU/hr
1VY03A Row # 1 with adjusted length of 102.75" at 72.5 gpm:	121,197 BTU/hr
Difference between two cases at 72.5 gpm:	2,225 BTU/hr
Adjustment for impact of 2 out of 24 tubes (i.e., 2 twenty-fourths):	185.4 BTU/hr
Total coil with nominal length of 108.00" at 72.5 gpm:	938,124 BTU/hr
Total coil with estimate with missing fins at 72.5 gpm:	937,938.6 BTU/hr
Overall impact of missing fins (%) at 72.5 gpm:	-0.020%

The missing fins on two of the 24 tubes in the first row of 1VY03A appear to have a negligible affect on the overall thermal performance of the cooler.

The PROTO-HX™ reports associated with the assessment are included in Attachment I.

7.5 Fouling Sensitivity Analysis

The results of the fouling sensitivity analysis are included in Table 12. The PROTO-HX™ reports associated with the fouling sensitivity analysis and a graphical presentation of the results are included as Attachment M. It should be noted that neither the Table below or the figure in Attachment M have taken analytical uncertainty into account since the intent of this exercise is to assess the change in thermal margin (i.e., the slope of the curves in Attachment M). Analytical uncertainty treated as a bias on the results will have a negligible effect on the slope of the curves. Consideration of uncertainty would, however, change the point at which a thermal margin of 0% is reached.

Table 12: Fouling Sensitivity Analysis -- 1(2)VY03A at 72.5 gpm

Air-Side *f*	Tube-Side *f*	Required q	Available q	%Margin
0.0020	0.0000	722,217	1,002,563	38.82%
0.0020	0.0010	722,217	969,164	34.19%
0.0020	0.0020	722,217	938,124	29.90%
0.0020	0.0030	722,217	907,127	25.60%
0.0020	0.0040	722,217	879,956	21.84%

8. CONCLUSIONS

A model for the LaSalle County Station Units 1 & 2 SE Cubicle Area Coolers was developed using PROTO-HX™ Version 3.01. The model was benchmarked and validated using the performance specifications provided by the cooler vendor. The close correlation with vendor specified and model predicted thermal performance confirms that the models are to be considered acceptable for use in the GL 89-13 heat exchanger testing program and related performance analyses.

The available thermal margin for the coolers has been defined for the nameplate rated flow of 180 gpm and for a reduced flow rate of **72.5** gpm in support of service water system re-balancing efforts. Inclusion of a conservative assessment of the uncertainty in the analytical methods of PROTO-HX™ has provided high confidence in the thermal margins defined by the model for all cases.

The model database is saved under file name vy-03a.phx, with a file size of 1,277,952 bytes, and a file date and time of 7/6/98 at 6:21:52 pm. The saved database is set up to run the 72.5 gpm case with adjusted design fouling factors of 0.002 air-side and 0.002 tube-side. The database file is included as Attachment N.

9. REFERENCES

1. Heat Exchanger Thermal Performance Modeling Software Program PROTO-HX™ Version 3.01 Software Validation and Verification Report (SVVR) SQA No. SVVR-93948-02, Revision E, dated 11/5/97

2. LaSalle Calculation L-001077, Revision 2, RHR Pump A Cubicle Cooler Ventilation System

3. Procedure LTS-200-19, Revision 4, performed on cooler 1VY03A on 6/12/98

4. LaSalle Station Updated Final Safety Analysis Report, Table 3.11-8, Harsh Environment Zone H6 -- Bounding Environmental Conditions Inside the ECCS Cubicles (Attachment A)

5. LaSalle Station Updated Final Safety Analysis Report, Section 9.2.1, ECCS Equipment Cooling Water System (excerpt - Attachment A)

6. LaSalle Station Updated Final Safety Analysis Report, Section 9.2.6, Ultimate Heat Sink (excerpt - Attachment A)

7. Drawing Number 28SW404543, "CSCS Equipment Area Cooling Coils," original issue, 7/21/76 (Attachment A)

8. LaSalle Calculation L-000581, Revision 0, Evaluation of the CSCS Cubicle Area Coolers Operation with a Reduced Cooling Water Inlet Temperature

9. Piping and Instrumentation Drawing M-87, Sheet 3, "CSCS Equipment Cooling Water System," Revision F dated 5/4/88

10. Piping and Instrumentation Drawing M-134, Sheet 3, "CSCS Equipment Cooling Water System," Revision F dated 5/25/82

11. Bahnson Drawings 2605-1-11,12,13, & 14 (Attachment A)

12. Standards of the Tubular Exchanger Manufacturers Association (TEMA), Seventh Edition, 1988

13. Specification Number J-2582, Heat Exchange Coils and Cabinets, La Salle County - Units 1 and 2, Revision 1, dated 1/16/75 (excerpt - Attachment A)

14. Proto-Power Calculation 96-069, Revision -, Fluid Properties - Moist Air - Range 8° to 300°F

15. *Compact Heat Exchangers*, W.M. Kays and A.L. London, McGraw Hill, Third Edition, 1984. (excerpt - Attachment C)

16. 1997 ASHRAE Handbook -- Fundamentals, inch pound Edition, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA (excerpt - Attachment A)

17. Drawing M-1366, Sheet 1, "Reactor Building Ventilation System -- Elevation 694'-6" East," Revision H dated 4/29/83

18. Drawing M-1464, "CSCS Equipment Cooling System," Revision B dated 5/12/88

19. Drawing M-1465, "CSCS Equipment Cooling System," Revision B dated 5/12/88

20. Coil Walkdown Data, ComEd NDIT No. LS-0847 dated 7/6/98 (Attachment L)

Attachment A to
Proto-Power Calculation
97-199
Revision A

Reference 4

TABLE 3.11-8

HARSH ENVIRONMENT ZONE H6 - BOUNDING ENVIRONMENTAL CONDITIONS INSIDE THE ECCS CUBICLES (EXCLUDING LPCS/RCIC CUBICLE) IN THE REACTOR BUILDING

WHEN THE ECCS EQUIPMENT IS OPERATING

The maximum cubicle temperature is 148°F, 90% relative humidity and at atmospheric pressure for the duration of 100 days. The total number of hours the cubicle is at 148°F will be ~22,110 hours (~921 days). The 100 days accident conditions are included. |

Radiation: 1 x 10^7 rads gamma (integrated)

Pressure: -0.4 inch W.G.

1(2)VY03A

NOTE: The bounding radiation dose $\geq$ (normal service radiation dose integrated over 40 years + accident does + 10% margin on the accident dose per IEEE 323-1974, Section 6.3.2.5).

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Reference 5

4. RHR pump seal cooler ('A' and 'B' RHR pumps only) - 20 gpm
5. LPCS pump motor cooling coil - 4 gpm
6. northwest cubicle area cooling coil - 150 gpm
7. southwest cubicle area cooling coil - 150 gpm
8. northeast cubicle area cooling coil - 200 gpm
9. southeast cubicle area cooling coil - 180 gpm
10. emergency makeup to fuel pool - 50 gpm minimum
11. containment flood - 300 gpm maximum.

b. System classifications are as shown in Section 3.2. All portions of this system are protected from the effects of tornados, missiles, pipe whip, and flooding.

c. To meet single failure criteria, the CSCS-ECWS for each unit is designed as three independent subsystems, one of which is shared between units (Drawing Nos. M-87 and M-134).

d. Strainers are provided to prevent plugging of cooled component heat transfer passages. All strainers include provisions for backwashing without significantly affecting system operation.

Organic fouling of heat transfer surfaces will be minimized by the chemical feed system which will treat the service water tunnel inlet flow with oxidizing biocides. However, the chemical feed system should not be considered auxiliary equipment required for the CSCS-ECW systems to perform their function. Therefore, the operability of the CSCS-ECW systems should not be tied to the operability of the chemical feed system. Connections and isolation valves are also provided immediately upstream and downstream of each cooled component for injection and circulation of biocidal agents, if necessary.

e. To detect leakage of radioactivity to the environment, radiation monitors are installed in the CSCS-ECWS immediately downstream of cooled components that contain radioactive fluids. The CSCS-ECWS discharge lines from these components are capable of remote manual isolation from the main control room.

f. Design of system piping and components is based on a 40-year life. Exterior surfaces of all buried system piping is protected by bituminous coatings and wrappings and provisions for cathodic protection are installed where such protection is found to be required based on electrical potential measurements. The design of all system piping includes a corrosion allowance of at least 0.08 inches.

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the normally closed portions the integrity and operability are checked.

9.2.6 Ultimate Heat Sink

The ultimate heat sink (UHS) provides sufficient cooling water to permit the safe shutdown and cooldown of the station for 30 days with no makeup for both normal and accident conditions.

9.2.6.1 Design Bases

9.2.6.1.1 Safety Design Bases

The ultimate heat sink has the following design bases:

a. to provide sufficient water volume permitting a safe shutdown and cooldown of the station for 30 days with no water makeup for both normal operating and accident conditions - the maximum permissible water temperature supplied to the plant is taken as 100° F;

b. to withstand the most severe postulated natural phenomenon as discussed in Chapter 2.0;

c. to withstand the postulated site-related incidents as discussed in Subsection 2.5.5; and

d. to provide water for fire protection equipment.

A more detailed physical description of the ultimate heat sink is provided in Sections 2.4 and 2.5.

9.2.6.1.2 Power Generation Design Bases

The ultimate heat sink, as a safety system, is not used during normal plant operations. Therefore, the ultimate heat sink has no power generation bases.

9.2.6.2 System Description

In the unlikely event that the main dike is breached, the cooling lake for the La Salle County Station is designed to hold 460 acre-feet of water with a surface area of 83 acres. This remaining water constitutes the ultimate heat sink for the station, and has a depth of approximately 5 feet and a top water elevation established at 690 feet. Figures 2.4-4 and 9.2-1 illustrate the physical layout and area capacity of the ultimate heat sink.

9.2.6.3 Safety Evaluation

The station's ultimate water requirements (Units 1 and 2) in gpm are summarized below.

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NDIVIDUAL COIL					PERFOR[illegible]ATA													
UBE CE	ROWS	CIRCUIT-ING	FACE AREA (SQ.FT)	MARK FOR	SCFM	ENT. AIR TEMP.(°F) DB/WB	LVG. AIR TEMP.(°F) DB/WB	ENT. WATER TEMP.(°F)	LVG. WATER TEMP.(°F)	WATER GPM	TOTAL HEAT TRANSFER (BTU/H)(10⁶)	AIR SIDE PRESS.DROP (IN. H2O)	TUBE SIDE PRESS.DROP (FT. OF H2O)	DESIGN PRESSURE (PSIG)	DESIGN TEMP.(F°)	COIL QTY. PER UNIT	SHIPPING WGT. (LBS) PER COIL	[illegible]TING [illegible](LBS) PER COIL
24	10	FULL	52.6	1VY03A 2VY03A	25420	150/92	108.8/84	105.	117.7	180.	1.108	.73	34.0	250	200	2	1860	2080

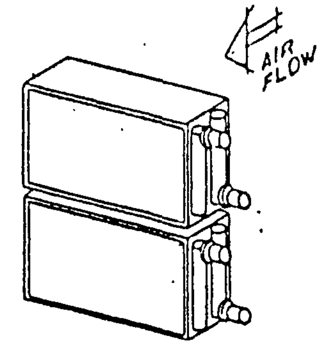
MATERIAL SPECIFICATIONS

TUBES - $\frac{3}{8}$ O.D. ASME SB75 COPPER, .049 WALL THICKNESS.

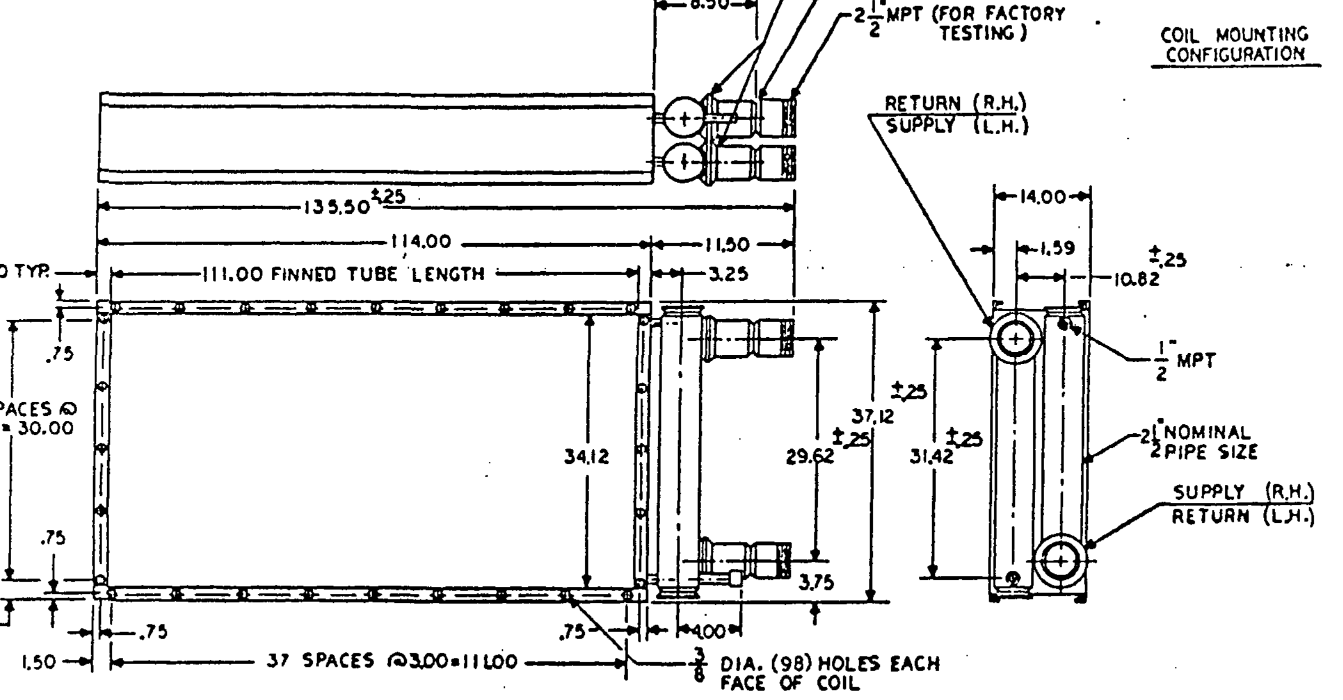
FINS - ASTM B209 ALUM. 0.012 IN. THK. SPIRAL TYPE MECHANICAL BOND, 10.0 FINS/INCH.

HEADERS - $2\frac{1}{2}$" NOM. SCH. 80 BLACK STEEL PIPE ASTM A53

CASING - ASTM A526, 14GA. GALV. STEEL



COIL MOUNTING CONFIGURATION



GENERAL TOLERANCES
DECIMALS ±.12
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES

JOB NAME LASALLE COUNTY POWER STATION-UNIT* 1/2
JOB LOCATION SENECA, ILLINOIS
BUYER COMMONWEALTH EDISON COMPANY
BUYER NO. 194871 CARRIER NO. 6300D2039
DIMENSIONS CERTIFIED BY D. Lockwood DATE 7-21-76

RAWN BY	THOMSON	6-23-76
H'KD BY	RDB	7.21.76

TE
SUPERSEDES

SAFETY RELATED HEAT RECOVERY COILS-CSCS EQUIP. AREA COOLING COILS

EQUIPMENT NO.(S)
1VY03A
2VY03A

DWG. NO. 28SW404553

REV.

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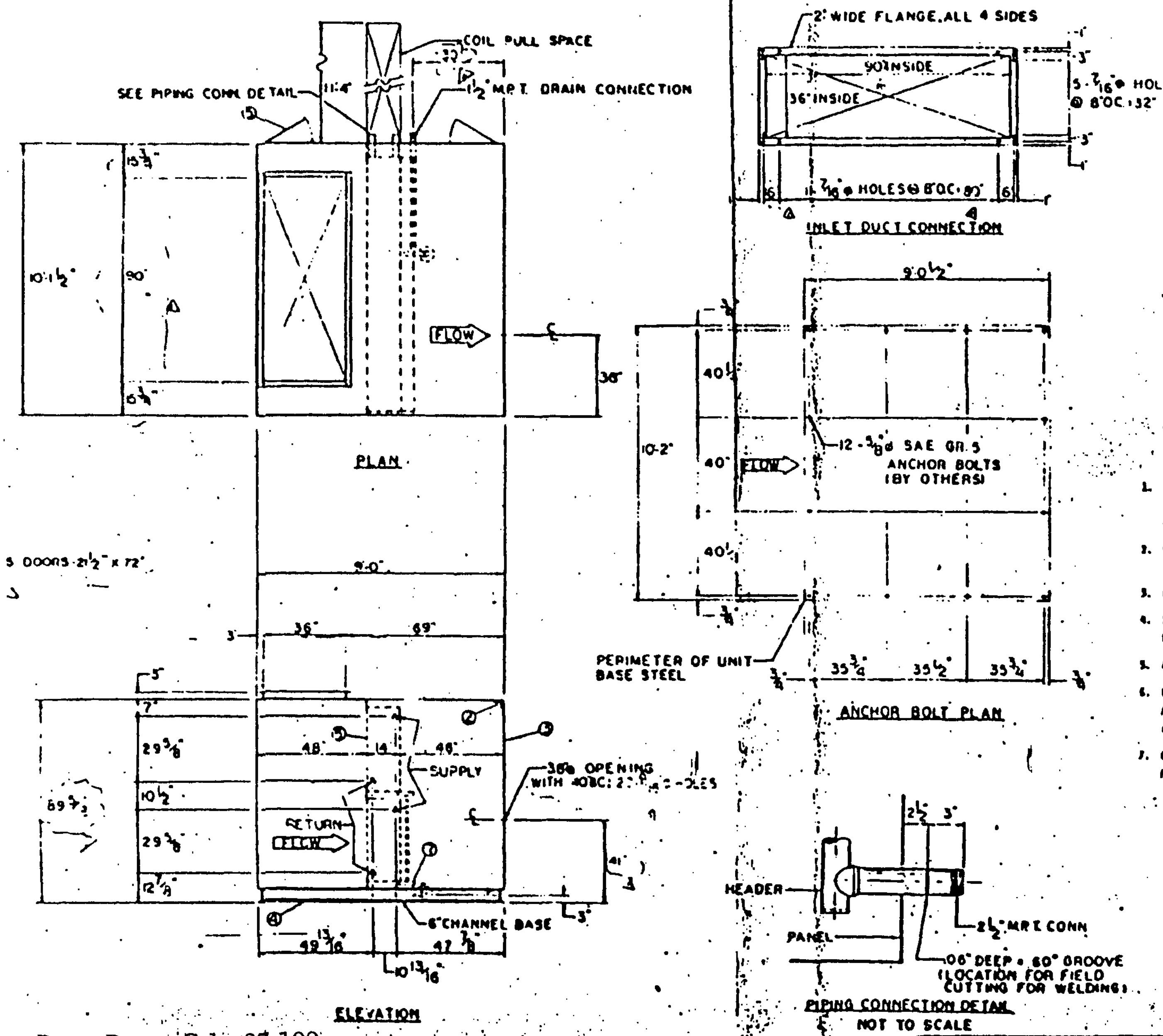
Reference 7



SARGENT & LUNDY SPEC. J-2582

SAFETY RELATED

BILL OF MATERIALS

1. UNIT COOLER DESIGNED TO COOL 25,420 SCFM FROM 150/90°F TO 100.5/60°F USING 180 GPM OF WATER FROM 105°F TO 117.7°F COMPLETE WITH THE FOLLOWING CONSTRUCTION AND EQUIPMENT. FACTORY ORDER NO. 8-0051L-130.
2. GROUP OF INTERNAL STRUCTURAL FRAMING (SPEC. 2). FACTORY ORDER NO. 8-0051L-130A.
3. GROUP OF ENCLOSURE PANELS (SPEC. 3). FACTORY ORDER NO. 8-0051L-130B.
4. STRUCTURAL STEEL BASE WITH LIFTING LUGS (SPEC. 2). FACTORY ORDER NO. 8-0051L-130C.
5. ACCESS DOORS (SPEC. 4). FACTORY ORDER NO. 8-0051L-130D.
6. COOLING COILS 24 TFX 111 FT. 10 ROWS FULL CIRCUIT RATED 1,380,000 BTUH AIR PRESSURE DROP 0.73 IN. WATER, WATER PRESSURE DROP 14 FT. WATER (SPEC. 6 & 8A). FACTORY ORDER NO. 8-0051L-130E.
7. COOLING COIL DRIP PANS CONSTRUCTED FROM 16 GAUGE 304 STAINLESS STEEL. FACTORY ORDER NO. 8-0051L-130F.

• SEE DWG. 2605-15 FOR MAT'L SPECS

SHIPPING WEIGHT 7545#
OPERATING WEIGHT 7985#

LEFT HAND UNIT
ALL DIMENSIONS ± 1/4"

0' 1' 2' 3' 4' 5'
0 6 12
GRAPHIC SCALE

LASALLE COUNTY POWER STA UNITS 1 & 2
SENECA, ILLINOIS
COMMONWEALTH EDISON CO
194171
6520020318

Reference 11

REVISED AS NOTED

ECOA	DATE	BAHNSON DWG NO	2605-16	
DRAWN BY				
CHECKED BY				

CSCS EQUIP AREA COIL CABINET
1VY03A

BBC-100-13 2

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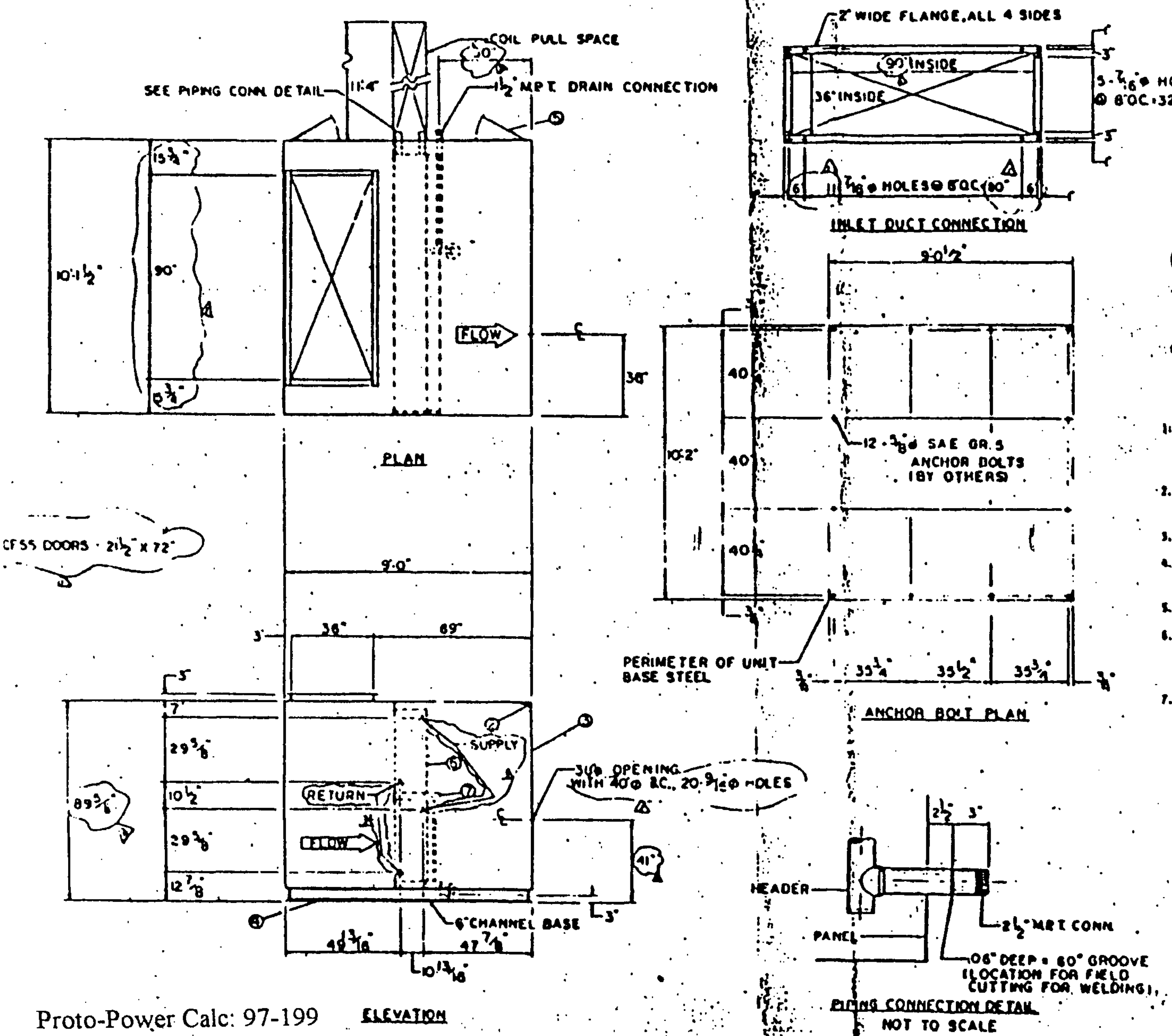

SARGENT & LUNDY J-2582

SAFETY RELATED

BILL OF MATERIALS

1. UNIT COOLER DESIGNED TO COOL 25,420 SCFM FROM 150/92°F TO 108.1/89°F USING 180 GPM OF WATER FROM 105°F TO 117.7°F COMPLETE WITH THE FOLLOWING CONSTRUCTION AND EQUIPMENT. FACTORY ORDER NO. 8-00510-130.
2. GROUP OF INTERNAL STRUCTURAL FRAMING (SPEC. 2). FACTORY ORDER NO. 8-00510-130A.
3. GROUP OF ENCLOSURE PANELS (SPEC. 3). FACTORY ORDER NO. 8-00510-130B.
4. STRUCTURAL STEEL BASE WITH LIFTING LUGS (SPEC. 3). FACTORY ORDER NO. 8-00510-130C.
5. ACCESS DOORS (SPEC. 4). FACTORY ORDER NO. 8-00510-130D.
6. COOLING COILS 24 FPI 111 FTL 10 ROWS CIRCUIT RATED 1,307,000 BTUH AIR PRESSURE DROP 0.73 IN. WATER, WATER PRESSURE DROP 30 FT. W.G. (SPEC. 6 & 6A). FACTORY ORDER NO. 8-00510-130E.
7. COOLING COIL DRIP PANS CONSTRUCTED FROM 16 GAUGE 304 STAINLESS STEEL. FACTORY ORDER NO. 8-00510-130F.

SEE DWG. 2605-L-8 FOR MAT'L SPEC'S

SHIPPING WEIGHT 7545#
OPERATING WEIGHT 7985#

LEFT HAND UNIT
ALL DIMENSIONS ± ⅛"

0' 1' 2' 3' 4' 5'
0 6 12
GRAPHIC SCALE

Reference 11

LASALLE COUNTY POWER STA. UNITS 1&2
SENECA ILLINOIS
COMMONWEALTH EDISON CO.
194871 S5002013

REVISED PER SARGENT & LUNDY COMMENTS
Ⓒ REVISED AS NOTED

BCOA		DATE		BAHNSON DWG NO	2605-L-18

DRAWN BY		
CHECKED BY		

CSCS EQUIP AREA COIL CABINET

2VY03A

BBC-100-14

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GENERAL
QUALITY ASSURANCE
PROCEDURE

SARGENT & LUNDY
ENGINEERS
CHICAGO

TITLE & APPROVAL PAGE

Reference 13

"SAFETY RELATED ITEMS ARE PART OF THIS SPECIFICATION"

Client CECO
Specification Title Heat Exchange Coils and Cabinets
Specification Number J-2582
Project Identification La Salle County - Units 1 and 2
Project Number 4266-00/4267-00
Department Mechanical/HVAC

REV	DATE	PREPARER	APPROVER	PURPOSE OF ISSUE
1	1-16-75	P.N. Mehrotra	W K Brown	Issue to CECO for bids.

	Function or Service..........	Control Room	Auxiliary Electric Equipment	Primary Containment Vent.	CSCS Eqpt. Area Cooling	CSCS Eqpt. Area Cooling	CSCS Eqpt. Area Cooling	
	Equipment Numbers.............	OVC02AA OVC02AB	OVE01AA OVE01AB	1VP03AA 1VP03AB 2VP03AA 2VP03AB	1VY01A 1VY02A 2VY01A 2VY02A	1VY03A 2VY03A	1VY04A 2VY04A	
	Safety related or Nonsafety related (SR or NSR)...........	SR	SR	NSR	SR and ASME III	SR and ASME III	SR and ASME III	
403.	PERFORMANCE DATA (HEAT EXCHANGE COIL CABINETS)							
403.1	Mode of Operation...............	Cooling	Cooling	Cooling	Cooling	Cooling	Cooling	
a.	Entering Air Dry Bulb......(°F)	81.8	81.9	135	150	150	150	Add.1
b.	Entering Air Wet Bulb......(°F)	63.1	63.2	92	___	___	___	Add.1
c.	Leaving Air Dry Bulb.......(°F)	54.3	54.9	65	110	110	110	Add.1
d.	Leaving Air Wet Bulb.......(°F)	52.8	53.2	63	___	___	___	Add.1
e.	Actual Air Quantity at 70°F, 40% RH and Site Elevation.....................(ft^3/min)	26340	31300	50000	18000	26400	28500	
f.	Standard Air Quantity at .075 lb/ft^3............(Std ft^3/min)	25380	30100	48150	17330	25420	27450	
g.	Cooling Medium.................	R-22	R-22	Chilled Water	Water	Water	Water	
h.	Evaporator Refrigerant Temperature......................(°F)	42	42	___	___	___	___	Add.1
i.	Entering Water Temperature.(°F)	___	___	46	105.	105.	105.	
j.	Maximum Water Quantity(gal/min)	___	___	1200	150.	220.	240	
k.	Minimum Total Heat Exchange Capacity ....(Btu/h)	797,000	936,000	6.55×10^6	748,700	1.1×10^6	1.19×10^6	
l.	Minimum Sensible Heat Exchange Capacity ....(Btu/h)	725,000	847,000	3.63×10^6	748,700	1.1×10^6	1.19×10^6	
m.	Maximum Coil Face Velocity ....(ft/min)	600	600	600	700	700	700	

4-7

Reference 13

J-2582
Add. 1

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Reference 16

Table 1A Heating and Wind Design Conditions—United States

							Heating DB		Extreme Wind Speed			Coldest Month WS/MDB				MWS/MWD to DB				Annual Extreme Daily			
												0.4%		1%		99.6%		0.4%		Mean DB		StdD DB	
Station	WMO#	Lat.	Long.	Elev. ft	StdP psia	Dates	99.6%	99%	1%	2.5%	5%	WS	MDB	WS	MDB	MWS	PWD	MWS	PWD	Max	Min	Max	Min
West Palm Beach	722030	26.68	80.12	20	14.685	6193	43	47	24	21	19	24	69	21	70	9	320	12	110	94	35	2.0	5.0
GEORGIA																							
Albany	722160	31.53	84.18	194	14.593	8293	27	30	19	17	15	19	50	16	50	4	360	9	250	100	17	2.2	7.2
Athens	723110	33.95	83.32	810	14.270	6193	20	25	19	17	15	20	40	18	40	10	290	9	270	95	11	3.5	6.6
Atlanta	722190	33.65	84.42	1033	14.155	6193	18	23	22	19	17	23	37	21	36	12	320	9	300	96	9	3.5	7.3
Augusta	722180	33.37	81.97	148	14.617	6193	21	25	20	18	15	21	45	19	46	5	290	9	250	100	13	3.7	5.6
Brunswick	722137	31.15	81.38	20	14.683	8293	30	34	18	17	16	19	49	18	49	8	350	10	250	98	22	2.5	7.1
Columbus, Fort Benning	722250	32.33	85.00	233	14.572	8293	23	27	16	13	11	17	46	15	46	3	320	5	240	100	14	2.9	6.7
Columbus, Metro Airport	722255	32.52	84.93	397	14.486	6193	23	27	17	15	14	15	44	16	46	7	310	9	310	99	14	2.3	6.1
Macon	722170	32.70	83.65	361	14.505	6193	23	27	19	17	15	20	46	18	45	7	320	9	270	100	14	2.7	6.4
Marietta, Dobbins AFB	722270	33.92	84.52	1070	14.136	8293	21	26	18	16	13	20	35	15	38	9	340	6	300	97	12	3.6	6.7
Rome	723200	34.35	85.17	643	14.357	8293	15	21	14	12	10	14	42	13	42	5	340	6	270	98	4	3.8	7.0
Savannah	722070	32.13	81.20	49	14.669	6193	26	29	20	17	15	21	49	19	49	7	270	9	270	98	18	3.0	5.4
Valdosta, Moody AFB	747810	30.97	83.20	233	14.572	8293	30	34	15	13	12	16	53	14	52	4	160	5	300	99	21	2.5	7.6
Valdosta, Regional Airport	722166	30.78	83.28	203	14.588	8293	28	31	17	15	14	18	55	16	56	4	340	8	300	99	17	3.2	7.7
Waycross	722130	31.25	82.40	151	14.615	8293	29	32	16	14	12	16	52	14	52	4	250	7	240	98	21	7	7.6
HAWAII																							
Ewa, Barbers Point NAS	911780	21.32	158.07	49	14.669	8293	59	61	20	18	16	22	73	19	73	5	40	11	60	93	35	1.6	21.4
Hilo	912850	19.72	155.07	36	14.676	6193	61	63	19	16	14	21	76	18	76	7	230	12	110	88	58	1.6	1.8
Honolulu	911820	21.35	157.93	16	14.687	6193	61	63	23	21	20	23	74	21	75	5	320	15	60	91	58	1.9	2.2
Kahului	911900	20.90	156.43	66	14.661	6193	59	61	27	25	24	32	76	28	76	6	160	19	50	92	54	1.5	4.7
Kaneohe, MCAS	911760	21.45	157.77	10	14.690	8293	67	68	20	18	17	21	74	19	74	7	190	10	70	88	40	1.4	29.0
Lihue	911650	21.98	159.35	148	14.617	6193	60	62	26	24	21	25	73	23	73	8	270	14	60	87	57	1.4	3.0
Molokai	911860	21.15	157.10	449	14.458	8293	60	61	24	22	21	22	74	21	74	4	70	13	60	92	43	4	22.0
IDAHO																							
Boise	726810	43.57	116.22	2867	13.235	6193	2	9	24	21	18	22	37	19	37	6	130	11	320	103	−4	2.7	9.1
Burley	725867	42.55	113.77	4150	12.621	8293	−5	2	23	21	19	23	30	22	28	7	60	8	280	98	−11	4	8.5
Idaho Falls	725785	43.52	112.07	4741	12.346	8293	−12	−6	27	23	21	28	32	23	29	7	360	12	180	96	−20	3.6	9.0
Lewiston	727830	46.38	117.02	1437	13.948	8293	6	15	20	17	14	24	38	20	40	5	280	7	310	103	3	2.7	9.9
Mountain Home, AFB	726815	43.05	115.87	2995	13.173	8293	0	5	23	21	18	23	33	21	31	2	90	8	350	105	−6	3.2	8.5
Mullan	727836	47.47	115.80	3317	13.017	8293	−1	7	10	10	9	11	18	9	21	2	10	4	10	92	−7	2	7.9
Pocatello	725780	42.92	112.60	4478	12.468	6193	−7	0	29	25	23	30	36	27	36	6	50	11	250	98	−15	2.3	9.1
ILLINOIS																							
Belleville, Scott AFB	724338	38.55	89.85	453	14.457	8293	3	10	21	18	15	23	32	20	31	7	360	7	190	100	−3	3.1	7.2
Chicago, Meigs Field	725340	41.78	87.75	623	14.367	8293	−4	3	23	22	19	26	17	23	30	12	240	13	220	97	−10	3.2	8.1
Chicago, O'Hare Int'l A	725300	41.98	87.90	673	14.342	6193	−6	−1	26	23	21	27	24	23	23	10	270	12	230	96	−12	2.8	6.5
Decatur	725316	39.83	88.87	682	14.337	8293	−2	3	24	22	20	27	24	24	27	13	310	12	210	99	−10	5.8	6.2
Glenview, NAS	725306	42.08	87.82	653	14.352	8293	−3	4	22	19	17	23	17	20	25	11	250	10	240	98	−10	3.1	7.7
Marseilles	744600	41.37	88.68	738	14.308	8293	−5	1	26	22	20	28	18	25	21	12	290	10	250	96	−11	4	5.9
Moline/Davenport IA	725440	41.45	90.52	594	14.383	6193	−8	−3	26	23	20	28	16	24	18	9	290	12	200	97	−14	2.7	6.0
Peoria	725320	40.67	89.68	663	14.347	6193	−6	−1	25	22	20	26	16	23	19	9	290	11	180	96	−12	3.3	6.1
Quincy	724396	39.95	91.20	768	14.292	8293	−4	2	26	23	20	28	23	24	22	12	330	12	210	97	−10	3.6	8.3
Rockford	725430	42.20	89.10	741	14.306	6193	−10	−4	26	23	21	26	18	23	20	9	290	13	200	95	−16	3.1	5.5
Springfield	724390	39.85	89.67	614	14.373	6193	−4	2	25	23	21	27	25	24	27	10	270	12	230	97	−11	2.8	5.5
West Chicago	725305	41.92	88.25	758	14.297	8293	−7	0	23	21	19	25	13	23	20	11	290	11	240	96	−14	3.2	7.7
INDIANA																							
Evansville	724320	38.05	87.53	387	14.491	6193	3	9	22	19	17	22	33	20	34	7	320	9	240	97	−4	2.7	8.5
Fort Wayne	725330	41.00	85.20	827	14.262	6193	−4	2	25	23	20	27	19	24	22	10	250	12	230	95	−11	3.6	5.2
Indianapolis	724380	39.73	86.27	807	14.272	6193	−3	3	24	21	19	25	26	22	27	8	230	11	230	94	−10	2.8	6.8
Lafayette, Purdue Univ	724386	40.42	86.93	607	14.376	8293	−5	3	22	20	18	24	26	22	27	9	270	12	220	97	−11	3.8	7.7
Peru, Grissom AFB	725335	40.65	86.15	810	14.270	8293	−3	4	24	21	18	29	20	24	22	11	270	9	210	96	−8	3.8	7.4
South Bend	725350	41.70	86.32	774	14.289	6193	−2	3	25	23	20	26	22	23	23	13	230	12	230	95	−10	3.3	5.8
Terre Haute	724373	39.45	87.32	584	14.388	8293	3	5	23	20	18	23	31	21	32	8	150	11	230	96	−10	3.2	7.9
IOWA																							
Burlington	725455	40.78	91.13	699	14.328	8293	−4	1	21	19	17	24	12	21	18	9	310	11	200	98	−10	4	6.8
Cedar Rapids	725450	41.88	91.70	869	14.240	8293	−11	−5	25	22	20	29	12	26	14	10	300	11	180	96	−15	3.6	5.4
Des Moines	725460	41.53	93.65	965	14.190	6193	−9	−4	27	24	21	28	14	24	19	11	320	12	180	98	−15	3.4	5.1
Fort Dodge	725490	42.55	94.18	1165	14.087	8293	−13	−7	27	23	21	29	10	26	10	11	340	11	190	96	−17	4.9	4.9
Lamoni	725466	40.62	93.95	1122	14.109	8293	−6	0	19	17	15	21	23	19	20	7	320	9	210	99	−12	4.3	6.8
Mason City	725485	43.15	93.33	1214	14.062	6193	−15	−10	27	23	22	30	9	27	12	12	300	14	200	97	−23	3.6	11.4
Ottumwa	725465	41.10	92.45	846	14.251	8293	−5	0	29	26	23	31	20	28	24	13	320	15	200	98	−12	4	6.8
Sioux City	725570	42.40	96.38	1102	14.119	6193	−11	−6	29	25	22	31	14	28	16	11	320	14	180	99	−18	3.6	4.7
Spencer	726500	43.17	95.15	1339	13.998	8293	−16	−11	24	22	20	25	13	23	13	10	300	12	180	99	−20	6.3	4.0
Waterloo	725480	42.55	92.40	879	14.234	6193	−14	9	27	24	22	29	10	25	13	9	300	13	180	96	−20	3.5	5.9
KANSAS																							
Concordia	724580	39.55	97.65	1483	13.925	8293	−4	3	28	25	22	28	32	25	32	13	360	16	10	104	−8	4	9.4
Dodge City	724510	37.77	99.97	2592	13.370	6193	0	6	30	27	24	31	31	27	32	13	10	17	200	104	6	2.8	5.6
Ft Riley, Marshall AAF	724550	39.05	96.77	1066	14.138	8293	−2	5	21	18	16	20	39	18	37	5	350	9	180	104	−5	3.1	9.0
Garden City	724515	37.93	100.72	2890	13.224	8293	−3	4	30	26	23	29	32	25	34	12	360	16	190	104	−9	2.7	6.5
Goodland	724650	39.37	101.70	3688	12.840	6193	−3	2	32	28	24	31	27	27	30	12	270	13	180	102	−11	2.9	6.6

WMO# = World Meteorological Organization number
Lat = latitude
Long. = longitude
Elev = elevation, ft
StdP = standard pressure at station elevation, psia
DB = dry bulb temperature, °F
WS = wind speed, mph

Proto-Power Calc: 97-199
Attachment: A
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Reference 16

Table 3 Properties of Solids

Material Description	Specific Heat, Btu/lb·°F	Density, lb/ft^3	Thermal Conductivity, Btu/h·ft·°F	Emissivity	
				Ratio	Surface Condition
Aluminum (alloy 1100)	0.214[b]	171[u]	128[u]	0.09[n]	Commercial sheet
				0.20[n]	Heavily oxidized
Aluminum bronze (76% Cu, 22% Zn, 2% Al)	0.09[u]	517[u]	58[v]		
Asbestos: Fiber	0.25[b]	150[u]	0.097[u]		
Insulation	0.20[f]	36[b]	0.092[b]	0.93[b]	"Paper"
Ashes, wood	0.20[j]	40[b]	0.041[b] (122)		
Asphalt	0.22[b]	132[b]	0.43[b]		
Bakelite	0.35[b]	81[u]	9.7[u]		
Bell metal	0.086[t] (122)				
Bismuth tin	0.040*		37.6*		
Brick, building	0.2[b]	123[u]	0.4[b]	0.93*	
Brass: Red (85% Cu, 15% Zn)	0.09[u]	548[u]	87[v]	0.030[b]	Highly polished
Yellow (65% Cu, 35% Zn)	0.09[u]	519[u]	69[u]	0.033[b]	Highly polished
Bronze	0.104[t]	530[j]	17[j] (32)		
Cadmium	0.055[a]	540[j]	53.7[b]	0.02[d]	
Carbon (gas retort)	0.17[a]		0.20[b] (2)	0.81[a]	
Cardboard			0.04[b]		
Cellulose	0.32[b]	3.4[t]	0.033[t]		
Cement (portland clinker)	0.16[b]	120[f]	0.017[t]		
Chalk	0.215[t]	143[t]	0.48*	0.34*	About 250°F
Charcoal (wood)	0.20[f]	15[a]	0.03[a] (392)		
Chrome brick	0.17[b]	200[b]	0.67[b]		
Clay	0.22[b]	63[t]			
Coal	0.3[b]	90[t]	0.098[f] (32)		
Coal tars	0.35[b] (104)	75[b]	0.07[b]		
Coke (petroleum, powdered)	0.36[b] (752)	62[b]	0.55[b] (752)		
Concrete (stone)	0.156[b] (392)	144[b]	0.54[b]		
Copper (electrolytic)	0.092[u]	556[u]	227[u]	0.072[n]	Commercial, shiny
Cork (granulated)	0.485[t]	5.4[t]	0.028[t] (23)		
Cotton (fiber)	0.319[u]	95[u]	0.024[u]		
Cryolite ($AlF_3 \cdot 3NaF$)	0.253[b]	181[b]			
Diamond	0.147[b]	151[t]	27[t]		
Earth (dry and packed)		95[t]	0.037*	0.41*	
Felt		20.6[b]	0.03[b]		
Fireclay brick	0.198[b] (212)	112[t]	0.58[b] (392)	0.75[n]	At 1832°F
Fluorspar (CaF_2)	0.21[b]	199[v]	0.63[v]		
German silver (nickel silver)	0.09[u]	545[u]	19[u]	0.135[a]	Polished
Glass: Crown (soda-lime)	0.18[b]	154[u]	0.59[t] (200)	0.94[n]	Smooth
Flint (lead)	0.117[b]	267[u]	0.79[f]		
Heat-resistant	0.20[b]	139[t]	0.59[t] (200)		
"Wool"	0.157[b]	3.25[t]	0.022[t]		
Gold	0.0312[u]	1208[u]	172[t]	0.02[n]	Highly polished
Graphite: Powder	0.165*		0.106*		
Impervious	0.16[u]	117[u]	75[u]	0.75[b]	
Gypsum	0.259[b]	78[b]	0.25[b]	0.903[b]	On a smooth plate
Hemp (fiber)	0.323[u]	93[u]			
Ice: 32°F	0.487[t]	57.5[b]	1.3[b]	0.95*	
−4°F	0.465[t]		1.41*		
Iron: Cast	0.12[v] (212)	450[b]	27.6[b] (129)	0.435[b]	Freshly turned
Wrought		485[b]	34.9[b]	0.94[b]	Dull, oxidized
Lead	0.0309[u]	707[u]	20.1[u]	0.28[n]	Gray, oxidized
Leather (sole)		62.4[b]	0.092[b]		
Limestone	0.217[b]	103[b]	0.54[b]	0.36* to 0.90	At 145 to 380°F
Linen			0.05[b]		
Litharge (lead monoxide)	0.055[b]	490[b]			
Magnesia: Powdered	0.234[b] (212)	49.7[b]	0.35[b] (117)		
Light carbonate		13[b]	0.034[b]		
Magnesite brick	0.222[b] (212)	158[b]	2.2[b] (400)		
Magnesium	0.241[b]	108[u]	91[u]	0.55[n]	Oxidized
Marble	0.21[b]	162[b]	1.5[b]	0.931[b]	Light gray, polished
Nickel, polished	0.105[u]	555[u]	34.4[u]	0.045[n]	Electroplated
Paints: White lacquer				0.80[n]	
White enamel				0.91[n]	On rough plate
Black lacquer				0.80[n]	
Black shellac		63[u]	0.15[u]	0.91[n]	"Matte" finish
Flat black lacquer				0.96[n]	
Aluminum lacquer				0.39[n]	On rough plate

*Data source unknown.

Notes. 1. Values are for room temperature unless otherwise noted in parentheses

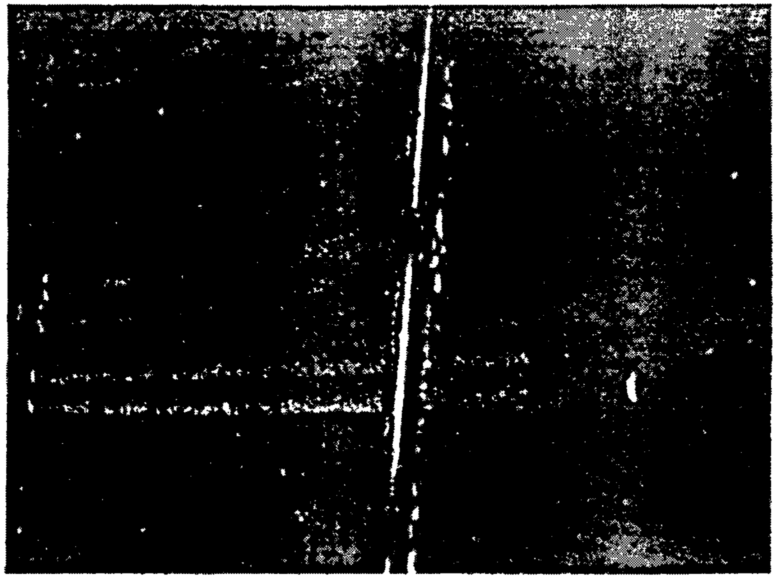
2. Superscript letters indicate data source from the section on References.

Attachment B to
Proto-Power Calculation
97-199
Revision A

LA SALLE COUNTY STATION
HEAT EXCHANGER
(WATER TO AIR)
DATABASE

EQUIPMENT NUMBER/ NAME	INSPECT DATE	BASE	PHOT	PHOTO STORAGE LOCATION	GENERAL APPEARANCE	TUBE CONDITION	FINS CONDITION	DEFECTS	CORRECTIVE ACTIONS RECOMMENDED	CORRECTIVE ACTIONS ACTUAL
1VY03C B/C RHR AREA COOLER	09/08/92	N	Y	BTN/XAPSHOT HX#1	VERY CLEAN, NO DEBRIS	NO VISIBLE DAMAGE OR LEAKS	MINOR FIN DAMAGE, BUT NO MORE THAN PREVIOUSLY. NO DIRT OR DEBRIS TRAPPED BETWEEN FINS.	NONE	NONE NEEDED	N/A

1VY03C 9/8/92



1VY03C 9/8/92

Attachment C to
Proto-Power Calculation
97-199
Revision A

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	CF-9.05-3/4J A
	j = EXP[-2.3333 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	111.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	180.00
Air Flow (acfm)	31,066.00
Tube Inlet Temp (°F)	105.00
Air Inlet Temp (°F)	150.0
Inlet Relative Humidity (%)	0.00
Inlet Wet Bulb Temp (°F)	92.00
Atmospheric Pressure	14.315

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	150.00	105.00
Outlet Temperature (°F)	109.56	117.96
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	10,824.91
LMTD	
Total Heat Transferred (BTU/hr)	1,157,626
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	1,157,626
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	150.00	115.26
Outlet Temperature (°F)	141.57	117.96
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	145.78	116.61
Skin Temperature (°F)	125.02	119.00
Velocity ***	4,509.16	5.53
Reynold's Number	1,005	38,835
Prandtl Number	0.7253	3.7653
Bulk Visc (lbm/ft·hr)	0.0491	1.3906
Skin Visc (lbm/ft·hr)		1.3592
Density (lbm/ft³)	0.0622	61.7634
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0163	0.3689

Tube-Side hi (BTU/hr·ft²·°F)	1,660.80
j Factor	0.0090
Air-Side ho (BTU/hr·ft²·°F)	12.06
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	7.70
Effective Area (ft²)	1,082.49
LMTD	28.95
Total Heat Transferred (BTU/hr)	241,422
Surface Effectiveness (Eta)	0.8977
Sensible Heat Transferred (BTU/hr)	241,422
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	114,411.37	89,409.99	Tube-Side hi (BTU/hr·ft²·°F)	1,639.05
Inlet Temperature (°F)	141.57	113.05	j Factor	0.0090
Outlet Temperature (°F)	134.66	115.26	Air-Side ho (BTU/hr·ft²·°F)	12.01
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02650655
Average Temp (°F)	138.11	114.15		
Skin Temperature (°F)	121.06	116.14	U Overall (BTU/hr·ft²·°F)	7.67
Velocity ***	4,509.16	5.53	Effective Area (ft²)	1,082.49
Reynold's Number	1,014	37,920	LMTD	23.78
Prandtl Number	0.7260	3.8651	Total Heat Transferred (BTU/hr)	197,591
Bulk Visc (lbm/ft·hr)	0.0486	1.4242		
Skin Visc (lbm/ft·hr)		1.3970	Surface Effectiveness (Eta)	0.8980
Density (lbm/ft³)	0.0630	61.8000	Sensible Heat Transferred (BTU/hr)	197,591
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0161	0.3680	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	114,411.37	89,409.99	Tube-Side hi (BTU/hr·ft²·°F)	1,621.18
Inlet Temperature (°F)	134.66	111.23	j Factor	0.0089
Outlet Temperature (°F)	129.01	113.05	Air-Side ho (BTU/hr·ft²·°F)	11.97
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02650655
Average Temp (°F)	131.83	112.14		
Skin Temperature (°F)	117.82	113.78	U Overall (BTU/hr·ft²·°F)	7.65
Velocity ***	4,509.16	5.52	Effective Area (ft²)	1,082.49
Reynold's Number	1,023	37,176	LMTD	19.55
Prandtl Number	0.7265	3.9501	Total Heat Transferred (BTU/hr)	161,922
Bulk Visc (lbm/ft·hr)	0.0482	1.4527		
Skin Visc (lbm/ft·hr)		1.4293	Surface Effectiveness (Eta)	0.8983
Density (lbm/ft³)	0.0636	61.8294	Sensible Heat Transferred (BTU/hr)	161,922
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0159	0.3673	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	129.01	109.75
Outlet Temperature (°F)	124.37	111.23
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	126.69	110.49
Skin Temperature (°F)	115.16	111.85
Velocity ***	4,509.16	5.52
Reynold's Number	1,030	36,570
Prandtl Number	0.7269	4.0221
Bulk Visc (lbm/ft·hr)	0.0479	1.4767
Skin Visc (lbm/ft·hr)		1.4568
Density (lbm/ft^3)	0.0641	61.8531
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3667

Tube-Side hi (BTU/hr·ft^2·°F)	1,606.48
j Factor	0.0089
Air-Side ho (BTU/hr·ft^2·°F)	11.94
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	7.63
Effective Area (ft^2)	1,082.49
LMTD	16.08
Total Heat Transferred (BTU/hr)	132,832
Surface Effectiveness (Eta)	0.8985
Sensible Heat Transferred (BTU/hr)	132,832
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	124.37	108.53
Outlet Temperature (°F)	120.56	109.75
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	122.46	109.14
Skin Temperature (°F)	112.98	110.26
Velocity ***	4,509.16	5.52
Reynold's Number	1,035	36,075
Prandtl Number	0.7272	4.0828
Bulk Visc (lbm/ft·hr)	0.0476	1.4970
Skin Visc (lbm/ft·hr)		1.4801
Density (lbm/ft^3)	0.0645	61.8722
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3662

Tube-Side hi (BTU/hr·ft^2·°F)	1,594.38
j Factor	0.0089
Air-Side ho (BTU/hr·ft^2·°F)	11.91
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	7.62
Effective Area (ft^2)	1,082.49
LMTD	13.23
Total Heat Transferred (BTU/hr)	109,063
Surface Effectiveness (Eta)	0.8987
Sensible Heat Transferred (BTU/hr)	109,063
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	120.56	107.52
Outlet Temperature (°F)	117.42	108.53
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	118.99	108.02
Skin Temperature (°F)	111.19	108.95
Velocity ***	4,509.16	5.52
Reynold's Number	1,040	35,671
Prandtl Number	0.7275	4.1338
Bulk Visc (lbm/ft·hr)	0.0474	1.5140
Skin Visc (lbm/ft·hr)		1.4997
Density (lbm/ft^3)	0.0648	61.8877
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3658

Tube-Side hi (BTU/hr·ft^2·°F)	1,584.42
j Factor	0.0089
Air-Side ho (BTU/hr·ft^2·°F)	11.89
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	7.60
Effective Area (ft^2)	1,082.49
LMTD	10.89
Total Heat Transferred (BTU/hr)	89,612
Surface Effectiveness (Eta)	0.8989
Sensible Heat Transferred (BTU/hr)	89,612
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	117.42	106.70
Outlet Temperature (°F)	114.85	107.52
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	116.14	107.11
Skin Temperature (°F)	109.72	107.88
Velocity ***	4,509.16	5.52
Reynold's Number	1,044	35,339
Prandtl Number	0.7277	4.1764
Bulk Visc (lbm/ft·hr)	0.0472	1.5282
Skin Visc (lbm/ft·hr)		1.5162
Density (lbm/ft^3)	0.0651	61.9003
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3655

Tube-Side hi (BTU/hr·ft^2·°F)	1,576.22
j Factor	0.0089
Air-Side ho (BTU/hr·ft^2·°F)	11.87
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	7.59
Effective Area (ft^2)	1,082.49
LMTD	8.96
Total Heat Transferred (BTU/hr)	73,673
Surface Effectiveness (Eta)	0.8990
Sensible Heat Transferred (BTU/hr)	73,673
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	114,411.37	89,409.99	Tube-Side hi (BTU/hr·ft²·°F)	1,569.47
Inlet Temperature (°F)	114.85	106.02	j Factor	0.0089
Outlet Temperature (°F)	112.73	106.70	Air-Side ho (BTU/hr·ft²·°F)	11.86
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02650655
Average Temp (°F)	113.79	106.36		
Skin Temperature (°F)	108.50	106.99	U Overall (BTU/hr·ft²·°F)	7.58
Velocity ***	4,509.16	5.52	Effective Area (ft²)	1,082.49
Reynold's Number	1,047	35,067	LMTD	7.38
Prandtl Number	0.7278	4.2121	Total Heat Transferred (BTU/hr)	60,599
Bulk Visc (lbm/ft·hr)	0.0471	1.5400		
Skin Visc (lbm/ft·hr)		1.5300	Surface Effectiveness (Eta)	0.8991
Density (lbm/ft³)	0.0654	61.9106	Sensible Heat Transferred (BTU/hr)	60,599
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0155	0.3652	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	114,411.37	89,409.99	Tube-Side hi (BTU/hr·ft²·°F)	1,563.91
Inlet Temperature (°F)	112.73	105.46	j Factor	0.0088
Outlet Temperature (°F)	110.99	106.02	Air-Side ho (BTU/hr·ft²·°F)	11.85
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02650655
Average Temp (°F)	111.86	105.74		
Skin Temperature (°F)	107.51	106.26	U Overall (BTU/hr·ft²·°F)	7.58
Velocity ***	4,509.16	5.52	Effective Area (ft²)	1,082.49
Reynold's Number	1,050	34,844	LMTD	6.08
Prandtl Number	0.7279	4.2417	Total Heat Transferred (BTU/hr)	49,865
Bulk Visc (lbm/ft·hr)	0.0470	1.5499		
Skin Visc (lbm/ft·hr)		1.5415	Surface Effectiveness (Eta)	0.8992
Density (lbm/ft³)	0.0656	61.9190	Sensible Heat Transferred (BTU/hr)	49,865
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0155	0.3650	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 10(Dry)

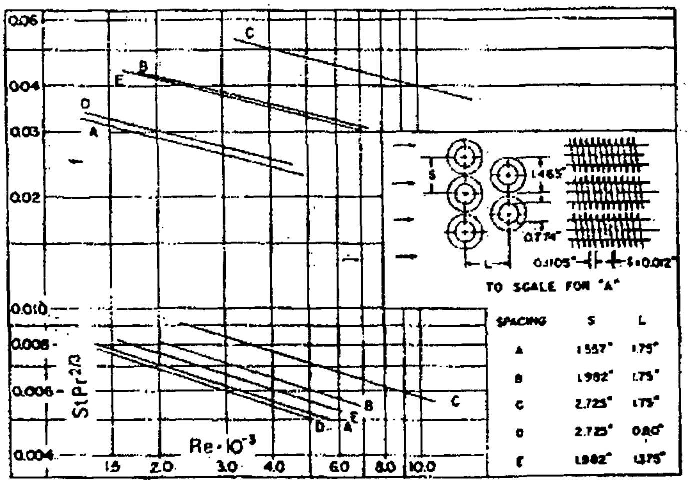
	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	110.99	105.00
Outlet Temperature (°F)	109.56	105.46
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	110.28	105.23
Skin Temperature (°F)	106.69	105.66
Velocity ***	4,509.16	5.52
Reynold's Number	1,053	34,661
Prandtl Number	0.7280	4.2664
Bulk Visc (lbm/ft·hr)	0.0469	1.5580
Skin Visc (lbm/ft·hr)		1.5511
Density (lbm/ft^3)	0.0657	61.9259
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0155	0.3648

Tube-Side hi (BTU/hr·ft^2·°F)	1,559.33
j Factor	0.0088
Air-Side ho (BTU/hr·ft^2·°F)	11.84
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	7.57
Effective Area (ft^2)	1,082.49
LMTD	5.01
Total Heat Transferred (BTU/hr)	41,046
Surface Effectiveness (Eta)	0.8993
Sensible Heat Transferred (BTU/hr)	41,046
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment D to
Proto-Power Calculation
97-199
Revision A

Fig. 10-89 Finned circular tubes, surface CF-9.05-3/4J. *(Data of Jameson.)*



SPACING	S	L
A	1.557"	1.75"
B	1.982"	1.75"
C	2.725"	1.75"
D	2.725"	0.80"
E	1.982"	1.375"

Tube outside diameter = 0.774 in = 19.66 × 10^{-3} m

Fin pitch = 9.05 per in = 356 per m

Fin thickness = 0.012 in = 0.305 × 10^{-3} m

Fin area/total area = 0.835

	A	B	C	D	E
Flow passage hydraulic diameter, $4r_h$ =	0.01681	0.02685	0.0445	0.01587	0.02108 ft
=	5.131 × 10^{-3}	8.179 × 10^{-3}	13.59 × 10^{-3}	4.846 × 10^{-3}	6.426 × 10^{-3} m
Free-flow area/frontal area, σ =	0.456	0.572	0.688	0.537	0.572
Heat transfer area/total volume, α =	108	85.1	61.9	135	108 ft^2/ft^3
=	354	279	203	443	354 m^2/m^3

Note: Minimum free-flow area in all cases occurs in the spaces transverse to the flow, except for *D*, in which the minimum area is in the diagonals.

Attachment E to
Proto-Power Calculation
97-199
Revision A

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	111.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	180.00
Air Flow (acfm)	31,066.00
Tube Inlet Temp (°F)	105.00
Air Inlet Temp (°F)	150.0
Inlet Relative Humidity (%)	0.00
Inlet Wet Bulb Temp (°F)	92.00
Atmospheric Pressure	14.315

Extrapolation Calculation Summary

	Air-Side	**Tube-Side**		
Mass Flow (lbm/hr)	114,411.37	89,409.99	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	150.00	105.00	j Factor	
Outlet Temperature (°F)	111.29	117.39	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	10,824.91
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	1,108,052
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	1,108,052
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	**Tube-Side**		
Mass Flow (lbm/hr)	114,411.37	89,409.99	Tube-Side hi (BTU/hr·ft^2·°F)	1,656.77
Inlet Temperature (°F)	150.00	115.04	j Factor	0.0069
Outlet Temperature (°F)	142.66	117.39	Air-Side ho (BTU/hr·ft^2·°F)	9.31
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
Average Temp (°F)	146.33	116.22		
Skin Temperature (°F)	123.53	118.30	U Overall (BTU/hr·ft^2·°F)	6.48
Velocity ***	4,509.16	5.53	Effective Area (ft^2)	1,082.49
Reynold's Number	1,004	38,688	LMTD	29.95
Prandtl Number	0.7253	3.7810	Total Heat Transferred (BTU/hr)	210,078
Bulk Visc (lbm/ft·hr)	0.0491	1.3959		
Skin Visc (lbm/ft·hr)		1.3683	Surface Effectiveness (Eta)	0.9185
Density (lbm/ft^3)	0.0621	61.7694	Sensible Heat Transferred (BTU/hr)	210,078
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3687	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	142.66	113.05
Outlet Temperature (°F)	136.46	115.04
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	139.56	114.05
Skin Temperature (°F)	120.24	115.82
Velocity ***	4,509.16	5.53
Reynold's Number	1,013	37,880
Prandtl Number	0.7259	3.8695
Bulk Visc (lbm/ft·hr)	0.0487	1.4256
Skin Visc (lbm/ft·hr)		1.4012
Density (lbm/ft³)	0.0628	61.8016
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3680

Tube-Side hi (BTU/hr·ft²·°F)	1,637.70
j Factor	0.0069
Air-Side ho (BTU/hr·ft²·°F)	9.28
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	6.46
Effective Area (ft²)	1,082.49
LMTD	25.38
Total Heat Transferred (BTU/hr)	177,423
Surface Effectiveness (Eta)	0.9188
Sensible Heat Transferred (BTU/hr)	177,423
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	136.46	111.37
Outlet Temperature (°F)	131.22	113.05
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	133.84	112.21
Skin Temperature (°F)	117.46	113.73
Velocity ***	4,509.16	5.52
Reynold's Number	1,020	37,203
Prandtl Number	0.7264	3.9470
Bulk Visc (lbm/ft·hr)	0.0484	1.4516
Skin Visc (lbm/ft·hr)		1.4301
Density (lbm/ft³)	0.0633	61.8283
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3673

Tube-Side hi (BTU/hr·ft²·°F)	1,621.52
j Factor	0.0069
Air-Side ho (BTU/hr·ft²·°F)	9.25
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	6.44
Effective Area (ft²)	1,082.49
LMTD	21.52
Total Heat Transferred (BTU/hr)	149,990
Surface Effectiveness (Eta)	0.9190
Sensible Heat Transferred (BTU/hr)	149,990
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Final Benchmark Case -- Custom Coil

Extrapolation Calculation for Row 4(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	131.22	109.95
Outlet Temperature (°F)	126.79	111.37
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	129.01	110.66
Skin Temperature (°F)	115.12	111.96
Velocity ***	4,509.16	5.52
Reynold's Number	1,026	36,633
Prandtl Number	0.7268	4.0145
Bulk Visc (lbm/ft·hr)	0.0481	1.4742
Skin Visc (lbm/ft·hr)		1.4553
Density (lbm/ft^3)	0.0638	61.8506
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3668

Tube-Side hi (BTU/hr·ft^2·°F)	1,607.81
j Factor	0.0069
Air-Side ho (BTU/hr·ft^2·°F)	9.23
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.42
Effective Area (ft^2)	1,082.49
LMTD	18.25
Total Heat Transferred (BTU/hr)	126,904
Surface Effectiveness (Eta)	0.9192
Sensible Heat Transferred (BTU/hr)	126,904
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	126.79	108.75
Outlet Temperature (°F)	123.04	109.95
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	124.91	109.35
Skin Temperature (°F)	113.13	110.46
Velocity ***	4,509.16	5.52
Reynold's Number	1,032	36,154
Prandtl Number	0.7271	4.0731
Bulk Visc (lbm/ft·hr)	0.0478	1.4937
Skin Visc (lbm/ft·hr)		1.4772
Density (lbm/ft^3)	0.0642	61.8692
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3663

Tube-Side hi (BTU/hr·ft^2·°F)	1,596.17
j Factor	0.0069
Air-Side ho (BTU/hr·ft^2·°F)	9.21
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.41
Effective Area (ft^2)	1,082.49
LMTD	15.48
Total Heat Transferred (BTU/hr)	107,447
Surface Effectiveness (Eta)	0.9193
Sensible Heat Transferred (BTU/hr)	107,447
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	123.04	107.73
Outlet Temperature (°F)	119.86	108.75
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	121.45	108.24
Skin Temperature (°F)	111.45	109.18
Velocity ***	4,509.16	5.52
Reynold's Number	1,037	35,749
Prandtl Number	0.7273	4.1238
Bulk Visc (lbm/ft·hr)	0.0476	1.5106
Skin Visc (lbm/ft·hr)		1.4963
Density (lbm/ft³)	0.0646	61.8847
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3659

Tube-Side hi (BTU/hr·ft²·°F)	1,586.30
j Factor	0.0069
Air-Side ho (BTU/hr·ft²·°F)	9.19
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	6.40
Effective Area (ft²)	1,082.49
LMTD	13.14
Total Heat Transferred (BTU/hr)	91,027
Surface Effectiveness (Eta)	0.9195
Sensible Heat Transferred (BTU/hr)	91,027
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	119.86	106.87
Outlet Temperature (°F)	117.16	107.73
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	118.51	107.30
Skin Temperature (°F)	110.02	108.10
Velocity ***	4,509.16	5.52
Reynold's Number	1,041	35,407
Prandtl Number	0.7275	4.1676
Bulk Visc (lbm/ft·hr)	0.0474	1.5252
Skin Visc (lbm/ft·hr)		1.5128
Density (lbm/ft³)	0.0649	61.8977
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3656

Tube-Side hi (BTU/hr·ft²·°F)	1,577.92
j Factor	0.0069
Air-Side ho (BTU/hr·ft²·°F)	9.18
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	6.39
Effective Area (ft²)	1,082.49
LMTD	11.15
Total Heat Transferred (BTU/hr)	77,156
Surface Effectiveness (Eta)	0.9196
Sensible Heat Transferred (BTU/hr)	77,156
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	117.16	106.13
Outlet Temperature (°F)	114.87	106.87
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	116.02	106.50
Skin Temperature (°F)	108.81	107.18
Velocity ***	4,509.16	5.52
Reynold's Number	1,044	35,119
Prandtl Number	0.7277	4.2053
Bulk Visc (lbm/ft·hr)	0.0472	1.5378
Skin Visc (lbm/ft·hr)		1.5270
Density (lbm/ft^3)	0.0651	61.9087
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3653

Tube-Side hi (BTU/hr·ft^2·°F)	1,570.80
j Factor	0.0068
Air-Side ho (BTU/hr·ft^2·°F)	9.17
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.38
Effective Area (ft^2)	1,082.49
LMTD	9.47
Total Heat Transferred (BTU/hr)	65,428
Surface Effectiveness (Eta)	0.9197
Sensible Heat Transferred (BTU/hr)	65,428
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	114.87	105.51
Outlet Temperature (°F)	112.94	106.13
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	113.90	105.82
Skin Temperature (°F)	107.79	106.41
Velocity ***	4,509.16	5.52
Reynold's Number	1,047	34,875
Prandtl Number	0.7278	4.2377
Bulk Visc (lbm/ft·hr)	0.0471	1.5485
Skin Visc (lbm/ft·hr)		1.5393
Density (lbm/ft^3)	0.0654	61.9179
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0155	0.3650

Tube-Side hi (BTU/hr·ft^2·°F)	1,564.76
j Factor	0.0068
Air-Side ho (BTU/hr·ft^2·°F)	9.16
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.38
Effective Area (ft^2)	1,082.49
LMTD	8.04
Total Heat Transferred (BTU/hr)	55,502
Surface Effectiveness (Eta)	0.9198
Sensible Heat Transferred (BTU/hr)	55,502
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	112.94	104.99
Outlet Temperature (°F)	111.29	105.51
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	112.11	105.25
Skin Temperature (°F)	106.92	105.74
Velocity ***	4,509.16	5.52
Reynold's Number	1,050	34,668
Prandtl Number	0.7279	4.2655
Bulk Visc (lbm/ft·hr)	0.0470	1.5578
Skin Visc (lbm/ft·hr)		1.5498
Density (lbm/ft^3)	0.0655	61.9257
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0155	0.3648

Tube-Side hi (BTU/hr·ft^2·°F)	1,559.62
j Factor	0.0068
Air-Side ho (BTU/hr·ft^2·°F)	9.15
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.37
Effective Area (ft^2)	1,082.49
LMTD	6.83
Total Heat Transferred (BTU/hr)	47,097
Surface Effectiveness (Eta)	0.9198
Sensible Heat Transferred (BTU/hr)	47,097
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

ComEd -- LaSalle
Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
Final Benchmark - Effective Coil Length

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000 ← *
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	180.00
Air Flow (acfm)	31,066.00
Tube Inlet Temp (°F)	105.00
Air Inlet Temp (°F)	150.0
Inlet Relative Humidity (%)	0.00
Inlet Wet Bulb Temp (°F)	92.00
Atmospheric Pressure	14.315

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	114,411.37	89,409.99	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	150.00	105.00	j Factor	
Outlet Temperature (°F)	111.46	117.35	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	10,532.34
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	1,103,074
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	1,103,074
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	114,411.37	89,409.99	Tube-Side hi (BTU/hr·ft^2·°F)	1,656.59
Inlet Temperature (°F)	150.00	115.02	j Factor	0.0069
Outlet Temperature (°F)	142.75	117.35	Air-Side ho (BTU/hr·ft^2·°F)	9.48
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
Average Temp (°F)	146.38	116.19		
Skin Temperature (°F)	123.61	118.30	U Overall (BTU/hr·ft^2·°F)	6.56
Velocity ***	4,634.41	5.53	Effective Area (ft^2)	1,053.23
Reynold's Number	1,032	38,677	LMTD	30.03
Prandtl Number	0.7253	3.7822	Total Heat Transferred (BTU/hr)	207,516
Bulk Visc (lbm/ft·hr)	0.0491	1.3963		
Skin Visc (lbm/ft·hr)		1.3683	Surface Effectiveness (Eta)	0.9172
Density (lbm/ft^3)	0.0621	61.7698	Sensible Heat Transferred (BTU/hr)	207,516
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3687	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	114,411.37	89,409.99	Tube-Side hi (BTU/hr·ft²·°F)	1,637.72
Inlet Temperature (°F)	142.75	113.06	j Factor	0.0069
Outlet Temperature (°F)	136.61	115.02	Air-Side ho (BTU/hr·ft²·°F)	9.45
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02650655
Average Temp (°F)	139.68	114.04		
Skin Temperature (°F)	120.34	115.85	U Overall (BTU/hr·ft²·°F)	6.54
Velocity ***	4,634.41	5.53	Effective Area (ft²)	1,053.23
Reynold's Number	1,041	37,878	LMTD	25.51
Prandtl Number	0.7259	3.8698	Total Heat Transferred (BTU/hr)	175,692
Bulk Visc (lbm/ft·hr)	0.0487	1.4257		
Skin Visc (lbm/ft·hr)		1.4009	Surface Effectiveness (Eta)	0.9175
Density (lbm/ft³)	0.0628	61.8017	Sensible Heat Transferred (BTU/hr)	175,692
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0161	0.3680	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	114,411.37	89,409.99	Tube-Side hi (BTU/hr·ft²·°F)	1,621.68
Inlet Temperature (°F)	136.61	111.39	j Factor	0.0068
Outlet Temperature (°F)	131.41	113.06	Air-Side ho (BTU/hr·ft²·°F)	9.42
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02650655
Average Temp (°F)	134.01	112.22		
Skin Temperature (°F)	117.58	113.77	U Overall (BTU/hr·ft²·°F)	6.52
Velocity ***	4,634.41	5.52	Effective Area (ft²)	1,053.23
Reynold's Number	1,048	37,207	LMTD	21.68
Prandtl Number	0.7264	3.9466	Total Heat Transferred (BTU/hr)	148,890
Bulk Visc (lbm/ft·hr)	0.0484	1.4515		
Skin Visc (lbm/ft·hr)		1.4295	Surface Effectiveness (Eta)	0.9177
Density (lbm/ft³)	0.0633	61.8282	Sensible Heat Transferred (BTU/hr)	148,890
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0160	0.3673	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	131.41	109.98
Outlet Temperature (°F)	127.00	111.39
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	129.21	110.68
Skin Temperature (°F)	115.24	112.01
Velocity ***	4,634.41	5.52
Reynold's Number	1,055	36,641
Prandtl Number	0.7267	4.0136
Bulk Visc (lbm/ft·hr)	0.0481	1.4739
Skin Visc (lbm/ft·hr)		1.4546
Density (lbm/ft^3)	0.0638	61.8503
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3668

Tube-Side hi (BTU/hr·ft^2·°F)	1,608.04
j Factor	0.0068
Air-Side ho (BTU/hr·ft^2·°F)	9.40
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.51
Effective Area (ft^2)	1,053.23
LMTD	18.43
Total Heat Transferred (BTU/hr)	126,279
Surface Effectiveness (Eta)	0.9179
Sensible Heat Transferred (BTU/hr)	126,279
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	127.00	108.78
Outlet Temperature (°F)	123.26	109.98
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	125.13	109.38
Skin Temperature (°F)	113.25	110.51
Velocity ***	4,634.41	5.52
Reynold's Number	1,060	36,163
Prandtl Number	0.7270	4.0720
Bulk Visc (lbm/ft·hr)	0.0478	1.4934
Skin Visc (lbm/ft·hr)		1.4765
Density (lbm/ft^3)	0.0642	61.8688
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3663

Tube-Side hi (BTU/hr·ft^2·°F)	1,596.45
j Factor	0.0068
Air-Side ho (BTU/hr·ft^2·°F)	9.38
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.49
Effective Area (ft^2)	1,053.23
LMTD	15.67
Total Heat Transferred (BTU/hr)	107,176
Surface Effectiveness (Eta)	0.9180
Sensible Heat Transferred (BTU/hr)	107,176
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	123.26	107.76
Outlet Temperature (°F)	120.08	108.78
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	121.67	108.27
Skin Temperature (°F)	111.56	109.23
Velocity ***	4,634.41	5.52
Reynold's Number	1,065	35,759
Prandtl Number	0.7273	4.1226
Bulk Visc (lbm/ft·hr)	0.0476	1.5102
Skin Visc (lbm/ft·hr)		1.4955
Density (lbm/ft³)	0.0645	61.8843
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3659

Tube-Side hi (BTU/hr·ft²·°F)	1,586.58
j Factor	0.0068
Air-Side ho (BTU/hr·ft²·°F)	9.36
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	6.48
Effective Area (ft²)	1,053.23
LMTD	13.33
Total Heat Transferred (BTU/hr)	91,017
Surface Effectiveness (Eta)	0.9182
Sensible Heat Transferred (BTU/hr)	91,017
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	120.08	106.89
Outlet Temperature (°F)	117.37	107.76
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	118.72	107.32
Skin Temperature (°F)	110.13	108.15
Velocity ***	4,634.41	5.52
Reynold's Number	1,069	35,417
Prandtl Number	0.7275	4.1664
Bulk Visc (lbm/ft·hr)	0.0474	1.5248
Skin Visc (lbm/ft·hr)		1.5120
Density (lbm/ft³)	0.0649	61.8974
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3656

Tube-Side hi (BTU/hr·ft²·°F)	1,578.19
j Factor	0.0068
Air-Side ho (BTU/hr·ft²·°F)	9.35
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	6.47
Effective Area (ft²)	1,053.23
LMTD	11.34
Total Heat Transferred (BTU/hr)	77,332
Surface Effectiveness (Eta)	0.9183
Sensible Heat Transferred (BTU/hr)	77,332
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	114,411.37	89,409.99	Tube-Side hi (BTU/hr·ft²·°F)	1,571.05
Inlet Temperature (°F)	117.37	106.16	j Factor	0.0068
Outlet Temperature (°F)	115.08	106.89	Air-Side ho (BTU/hr·ft²·°F)	9.34
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02650655
Average Temp (°F)	116.23	106.52		
Skin Temperature (°F)	108.91	107.23	U Overall (BTU/hr·ft²·°F)	6.46
Velocity ***	4,634.41	5.52	Effective Area (ft²)	1,053.23
Reynold's Number	1,073	35,127	LMTD	9.65
Prandtl Number	0.7277	4.2042	Total Heat Transferred (BTU/hr)	65,733
Bulk Visc (lbm/ft·hr)	0.0472	1.5374		
Skin Visc (lbm/ft·hr)		1.5263	Surface Effectiveness (Eta)	0.9184
Density (lbm/ft³)	0.0651	61.9084	Sensible Heat Transferred (BTU/hr)	65,733
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3653	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	114,411.37	89,409.99	Tube-Side hi (BTU/hr·ft²·°F)	1,564.97
Inlet Temperature (°F)	115.08	105.53	j Factor	0.0068
Outlet Temperature (°F)	113.12	106.16	Air-Side ho (BTU/hr·ft²·°F)	9.33
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02650655
Average Temp (°F)	114.10	105.84		
Skin Temperature (°F)	107.87	106.44	U Overall (BTU/hr·ft²·°F)	6.46
Velocity ***	4,634.41	5.52	Effective Area (ft²)	1,053.23
Reynold's Number	1,076	34,881	LMTD	8.22
Prandtl Number	0.7278	4.2368	Total Heat Transferred (BTU/hr)	55,895
Bulk Visc (lbm/ft·hr)	0.0471	1.5482		
Skin Visc (lbm/ft·hr)		1.5386	Surface Effectiveness (Eta)	0.9184
Density (lbm/ft³)	0.0653	61.9176	Sensible Heat Transferred (BTU/hr)	55,895
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3650	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	114,411.37	89,409.99
Inlet Temperature (°F)	113.12	105.00
Outlet Temperature (°F)	111.46	105.53
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	112.29	105.26
Skin Temperature (°F)	106.99	105.78
Velocity ***	4,634.41	5.52
Reynold's Number	1,079	34,673
Prandtl Number	0.7279	4.2648
Bulk Visc (lbm/ft·hr)	0.0470	1.5575
Skin Visc (lbm/ft·hr)		1.5493
Density (lbm/ft³)	0.0655	61.9255
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0155	0.3648

Tube-Side hi (BTU/hr·ft²·°F)	1,559.79
j Factor	0.0068
Air-Side ho (BTU/hr·ft²·°F)	9.32
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	6.45
Effective Area (ft²)	1,053.23
LMTD	7.00
Total Heat Transferred (BTU/hr)	47,543
Surface Effectiveness (Eta)	0.9185
Sensible Heat Transferred (BTU/hr)	47,543
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment F to
Proto-Power Calculation
97-199
Revision A

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Thermal Margin Assessment (Clean)

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Fouling Was Input by User

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	180.00
Air Flow (acfm)	28,445.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315
Input Fouling Factor	0.000000

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ComEd -- LaSalle

Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Thermal Margin Assessment (Clean)

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	105,113.87	89,504.32
Inlet Temperature (°F)	148.00	100.00
Outlet Temperature (°F)	104.31	112.84
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	10,532.34
LMTD	
Total Heat Transferred (BTU/hr)	1,148,793
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	1,148,793
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	105,113.87	89,504.32
Inlet Temperature (°F)	148.00	110.04
Outlet Temperature (°F)	138.46	112.84
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	143.23	111.44
Skin Temperature (°F)	114.13	114.06
Velocity ***	4,257.80	5.53
Reynold's Number	952**	36,957
Prandtl Number	0.7256	3.9804
Bulk Visc (lbm/ft·hr)	0.0489	1.4628
Skin Visc (lbm/ft·hr)		1.4254
Density (lbm/ft³)	0.0626	61.8395
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3671

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	1,618.75
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.96
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	7.55
Effective Area (ft²)	1,053.23
LMTD	31.54
Total Heat Transferred (BTU/hr)	250,885
Surface Effectiveness (Eta)	0.9214
Sensible Heat Transferred (BTU/hr)	250,885
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	105,113.87	89,504.32
Inlet Temperature (°F)	138.46	107.78
Outlet Temperature (°F)	130.78	110.04
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	134.62	108.91
Skin Temperature (°F)	111.10	111.05
Velocity ***	4,257.80	5.53
Reynold's Number	962**	36,030
Prandtl Number	0.7263	4.0932
Bulk Visc (lbm/ft·hr)	0.0484	1.5004
Skin Visc (lbm/ft·hr)		1.4685
Density (lbm/ft^{3})	0.0634	61.8754
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3661

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^{2}·°F)	1,596.04
j Factor	0.0070
Air-Side ho (BTU/hr·ft^{2}·°F)	8.92
Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00029413
Overall Fouling (hr·ft^{2}·°F/BTU)	
U Overall (BTU/hr·ft^{2}·°F)	7.52
Effective Area (ft^{2})	1,053.23
LMTD	25.51
Total Heat Transferred (BTU/hr)	201,932
Surface Effectiveness (Eta)	0.9217
Sensible Heat Transferred (BTU/hr)	201,932
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	105,113.87	89,504.32
Inlet Temperature (°F)	130.78	105.96
Outlet Temperature (°F)	124.59	107.78
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	127.68	106.87
Skin Temperature (°F)	108.66	108.61
Velocity ***	4,257.80	5.52
Reynold's Number	971**	35,289
Prandtl Number	0.7269	4.1878
Bulk Visc (lbm/ft·hr)	0.0480	1.5320
Skin Visc (lbm/ft·hr)		1.5049
Density (lbm/ft^{3})	0.0641	61.9036
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3654

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^{2}·°F)	1,577.67
j Factor	0.0070
Air-Side ho (BTU/hr·ft^{2}·°F)	8.88
Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00029413
Overall Fouling (hr·ft^{2}·°F/BTU)	
U Overall (BTU/hr·ft^{2}·°F)	7.49
Effective Area (ft^{2})	1,053.23
LMTD	20.65
Total Heat Transferred (BTU/hr)	162,834
Surface Effectiveness (Eta)	0.9219
Sensible Heat Transferred (BTU/hr)	162,834
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^{2}), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	105,113.87	89,504.32
Inlet Temperature (°F)	124.59	104.49
Outlet Temperature (°F)	119.59	105.96
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	122.09	105.22
Skin Temperature (°F)	106.68	106.64
Velocity ***	4,257.80	5.52
Reynold's Number	978**	34,695
Prandtl Number	0.7273	4.2668
Bulk Visc (lbm/ft·hr)	0.0476	1.5582
Skin Visc (lbm/ft·hr)		1.5355
Density (lbm/ft³)	0.0646	61.9260
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3648

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	1,562.80
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.86
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	7.46
Effective Area (ft²)	1,053.23
LMTD	16.73
Total Heat Transferred (BTU/hr)	131,505
Surface Effectiveness (Eta)	0.9221
Sensible Heat Transferred (BTU/hr)	131,505
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	105,113.87	89,504.32
Inlet Temperature (°F)	119.59	103.30
Outlet Temperature (°F)	115.54	104.49
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	117.56	103.89
Skin Temperature (°F)	105.08	105.05
Velocity ***	4,257.80	5.52
Reynold's Number	984**	34,217
Prandtl Number	0.7276	4.3324
Bulk Visc (lbm/ft·hr)	0.0473	1.5799
Skin Visc (lbm/ft·hr)		1.5609
Density (lbm/ft³)	0.0651	61.9438
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3643

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	1,550.75
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.84
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	7.44
Effective Area (ft²)	1,053.23
LMTD	13.57
Total Heat Transferred (BTU/hr)	106,333
Surface Effectiveness (Eta)	0.9223
Sensible Heat Transferred (BTU/hr)	106,333
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	105,113.87	89,504.32
Inlet Temperature (°F)	115.54	102.33
Outlet Temperature (°F)	112.27	103.30
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	113.91	102.82
Skin Temperature (°F)	103.78	103.76
Velocity ***	4,257.80	5.52
Reynold's Number	989**	33,833
Prandtl Number	0.7278	4.3867
Bulk Visc (lbm/ft·hr)	0.0471	1.5979
Skin Visc (lbm/ft·hr)		1.5821
Density (lbm/ft^3)	0.0654	61.9580
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0155	0.3639

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	1,540.98
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	8.82
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	
U Overall (BTU/hr·ft^2·°F)	7.43
Effective Area (ft^2)	1,053.23
LMTD	11.00
Total Heat Transferred (BTU/hr)	86,065
Surface Effectiveness (Eta)	0.9224
Sensible Heat Transferred (BTU/hr)	86,065
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	105,113.87	89,504.32
Inlet Temperature (°F)	112.27	101.55
Outlet Temperature (°F)	109.62	102.33
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	110.94	101.94
Skin Temperature (°F)	102.73	102.71
Velocity ***	4,257.80	5.52
Reynold's Number	993**	33,523
Prandtl Number	0.7280	4.4314
Bulk Visc (lbm/ft·hr)	0.0469	1.6127
Skin Visc (lbm/ft·hr)		1.5996
Density (lbm/ft^3)	0.0657	61.9694
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0155	0.3635

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	1,533.06
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	8.81
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	
U Overall (BTU/hr·ft^2·°F)	7.41
Effective Area (ft^2)	1,053.23
LMTD	8.93
Total Heat Transferred (BTU/hr)	69,716
Surface Effectiveness (Eta)	0.9225
Sensible Heat Transferred (BTU/hr)	69,716
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	105,113.87	89,504.32
Inlet Temperature (°F)	109.62	100.92
Outlet Temperature (°F)	107.47	101.55
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	108.54	101.24
Skin Temperature (°F)	101.88	101.86
Velocity ***	4,257.80	5.52
Reynold's Number	996**	33,272
Prandtl Number	0.7281	4.4682
Bulk Visc (lbm/ft·hr)	0.0467	1.6248
Skin Visc (lbm/ft·hr)		1.6140
Density (lbm/ft^3)	0.0660	61.9785
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0154	0.3633

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	1,526.63
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	8.80
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	
U Overall (BTU/hr·ft^2·°F)	7.40
Effective Area (ft^2)	1,053.23
LMTD	7.25
Total Heat Transferred (BTU/hr)	56,510
Surface Effectiveness (Eta)	0.9226
Sensible Heat Transferred (BTU/hr)	56,510
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	105,113.87	89,504.32
Inlet Temperature (°F)	107.47	100.41
Outlet Temperature (°F)	105.73	100.92
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	106.60	100.67
Skin Temperature (°F)	101.19	101.18
Velocity ***	4,257.80	5.52
Reynold's Number	999**	33,069
Prandtl Number	0.7282	4.4984
Bulk Visc (lbm/ft·hr)	0.0466	1.6348
Skin Visc (lbm/ft·hr)		1.6259
Density (lbm/ft^3)	0.0662	61.9859
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0154	0.3630

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	1,521.42
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	8.79
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	
U Overall (BTU/hr·ft^2·°F)	7.39
Effective Area (ft^2)	1,053.23
LMTD	5.89
Total Heat Transferred (BTU/hr)	45,830
Surface Effectiveness (Eta)	0.9227
Sensible Heat Transferred (BTU/hr)	45,830
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	105,113.87	89,504.32
Inlet Temperature (°F)	105.73	99.99
Outlet Temperature (°F)	104.31	100.41
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	105.02	100.20
Skin Temperature (°F)	100.63	100.62
Velocity ***	4,257.80	5.52
Reynold's Number	1,001	32,905
Prandtl Number	0.7283	4.5231
Bulk Visc (lbm/ft·hr)	0.0465	1.6429
Skin Visc (lbm/ft·hr)		1.6357
Density (lbm/ft³)	0.0664	61.9918
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0153	0.3629

Tube-Side hi (BTU/hr·ft²·°F)	1,517.18
j Factor	0.0069
Air-Side ho (BTU/hr·ft²·°F)	8.78
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	7.39
Effective Area (ft²)	1,053.23
LMTD	4.78
Total Heat Transferred (BTU/hr)	37,184
Surface Effectiveness (Eta)	0.9228
Sensible Heat Transferred (BTU/hr)	37,184
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment G to
Proto-Power Calculation
97-199
Revision A

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water	
Tube Fouling Factor	0.001500	←
Air-Side Fouling	0.000000	
Design Heat Transfer (BTU/hr)	1,108,000	
Atmospheric Pressure	14.315	
Sensible Heat Ratio	1.00	
Performance Factor (% Reduction)	0.000	
Heat Exchanger Type	Counter Flow	
Fin Type	Circular Fins	
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]	
Coil Finned Length (in)	108.000	←
Fin Pitch (Fins/Inch)	10.000	
Fin Conductivity (BTU/hr·ft·°F)	128.000	
Fin Tip Thickness (inches)	0.0120	
Fin Root Thickness (inches)	0.0120	
Circular Fin Height (inches)	1.452	
Number of Coils Per Unit	2	
Number of Tube Rows	10	
Number of Tubes Per Row	24.00	
Active Tubes Per Row	24.00	
Tube Inside Diameter (in)	0.5270	
Tube Outside Diameter (in)	0.6250	
Longitudinal Tube Pitch (in)	1.400	
Transverse Tube Pitch (in)	1.410	
Number of Serpentines	1.000	
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00	

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	180.00
Air Flow (acfm)	28,352.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Thermal Margin Assessment (Service)

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,770.20	89,504.32
Inlet Temperature (°F)	148.00	100.00
Outlet Temperature (°F)	106.16	112.28
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft^3)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft^2·°F)	
j Factor	
Air-Side ho (BTU/hr·ft^2·°F)	
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	
Effective Area (ft^2)	10,532.34
LMTD	
Total Heat Transferred (BTU/hr)	1,096,666
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	1,096,666
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,770.20	89,504.32
Inlet Temperature (°F)	148.00	109.87
Outlet Temperature (°F)	139.76	112.28
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	143.88	111.07
Skin Temperature (°F)	118.86	113.33
Velocity ***	4,243.88	5.53
Reynold's Number	948**	36,823
Prandtl Number	0.7255	3.9964
Bulk Visc (lbm/ft·hr)	0.0490	1.4681
Skin Visc (lbm/ft·hr)		1.4357
Density (lbm/ft^3)	0.0624	61.8447
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3669

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	1,614.82
j Factor	0.0071
Air-Side ho (BTU/hr·ft^2·°F)	8.94
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.28
Effective Area (ft^2)	1,053.23
LMTD	32.63
Total Heat Transferred (BTU/hr)	215,928
Surface Effectiveness (Eta)	0.9215
Sensible Heat Transferred (BTU/hr)	215,928
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,770.20	89,504.32
Inlet Temperature (°F)	139.76	107.85
Outlet Temperature (°F)	132.89	109.87
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	136.32	108.86
Skin Temperature (°F)	115.37	110.76
Velocity ***	4,243.88	5.53
Reynold's Number	957**	36,012
Prandtl Number	0.7262	4.0954
Bulk Visc (lbm/ft·hr)	0.0485	1.5012
Skin Visc (lbm/ft·hr)		1.4727
Density (lbm/ft^3)	0.0632	61.8761
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3661

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	1,595.10
j Factor	0.0071
Air-Side ho (BTU/hr·ft^2·°F)	8.90
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.26
Effective Area (ft^2)	1,053.23
LMTD	27.32
Total Heat Transferred (BTU/hr)	180,133
Surface Effectiveness (Eta)	0.9218
Sensible Heat Transferred (BTU/hr)	180,133
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,770.20	89,504.32
Inlet Temperature (°F)	132.89	106.17
Outlet Temperature (°F)	127.15	107.85
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	130.02	107.01
Skin Temperature (°F)	112.47	108.62
Velocity ***	4,243.88	5.52
Reynold's Number	965**	35,340
Prandtl Number	0.7267	4.1811
Bulk Visc (lbm/ft·hr)	0.0481	1.5297
Skin Visc (lbm/ft·hr)		1.5049
Density (lbm/ft^3)	0.0638	61.9017
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3654

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	1,578.58
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	8.88
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.24
Effective Area (ft^2)	1,053.23
LMTD	22.88
Total Heat Transferred (BTU/hr)	150,445
Surface Effectiveness (Eta)	0.9220
Sensible Heat Transferred (BTU/hr)	150,445
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,770.20	89,504.32
Inlet Temperature (°F)	127.15	104.76
Outlet Temperature (°F)	122.35	106.17
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	124.75	105.46
Skin Temperature (°F)	110.04	106.82
Velocity ***	4,243.88	5.52
Reynold's Number	971**	34,782
Prandtl Number	0.7271	4.2550
Bulk Visc (lbm/ft·hr)	0.0478	1.5543
Skin Visc (lbm/ft·hr)		1.5327
Density (lbm/ft³)	0.0643	61.9227
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0158	0.3649

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	1,564.74
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.85
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	6.23
Effective Area (ft²)	1,053.23
LMTD	19.18
Total Heat Transferred (BTU/hr)	125,772
Surface Effectiveness (Eta)	0.9222
Sensible Heat Transferred (BTU/hr)	125,772
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,770.20	89,504.32
Inlet Temperature (°F)	122.35	103.58
Outlet Temperature (°F)	118.33	104.76
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	120.34	104.17
Skin Temperature (°F)	108.01	105.32
Velocity ***	4,243.88	5.52
Reynold's Number	977**	34,318
Prandtl Number	0.7274	4.3184
Bulk Visc (lbm/ft·hr)	0.0475	1.5753
Skin Visc (lbm/ft·hr)		1.5567
Density (lbm/ft³)	0.0648	61.9401
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3644

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	1,553.14
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.83
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.02650655
U Overall (BTU/hr·ft²·°F)	6.21
Effective Area (ft²)	1,053.23
LMTD	16.08
Total Heat Transferred (BTU/hr)	105,231
Surface Effectiveness (Eta)	0.9223
Sensible Heat Transferred (BTU/hr)	105,231
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,770.20	89,504.32
Inlet Temperature (°F)	118.33	102.60
Outlet Temperature (°F)	114.97	103.58
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	116.65	103.09
Skin Temperature (°F)	106.31	104.05
Velocity ***	4,243.88	5.52
Reynold's Number	982**	33,931
Prandtl Number	0.7276	4.3727
Bulk Visc (lbm/ft·hr)	0.0473	1.5933
Skin Visc (lbm/ft·hr)		1.5772
Density (lbm/ft^3)	0.0651	61.9544
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3640

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	1,543.40
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	8.81
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.20
Effective Area (ft^2)	1,053.23
LMTD	13.49
Total Heat Transferred (BTU/hr)	88,105
Surface Effectiveness (Eta)	0.9225
Sensible Heat Transferred (BTU/hr)	88,105
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,770.20	89,504.32
Inlet Temperature (°F)	114.97	101.77
Outlet Temperature (°F)	112.16	102.60
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	113.56	102.19
Skin Temperature (°F)	104.89	103.00
Velocity ***	4,243.88	5.52
Reynold's Number	986**	33,609
Prandtl Number	0.7278	4.4189
Bulk Visc (lbm/ft·hr)	0.0471	1.6085
Skin Visc (lbm/ft·hr)		1.5948
Density (lbm/ft^3)	0.0655	61.9662
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0155	0.3636

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	1,535.25
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	8.80
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.19
Effective Area (ft^2)	1,053.23
LMTD	11.32
Total Heat Transferred (BTU/hr)	73,809
Surface Effectiveness (Eta)	0.9226
Sensible Heat Transferred (BTU/hr)	73,809
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104,770.20	89,504.32	Tube-Side hi (BTU/hr·ft²·°F)	1,528.40
Inlet Temperature (°F)	112.16	101.08	j Factor	0.0070
Outlet Temperature (°F)	109.80	101.77	Air-Side ho (BTU/hr·ft²·°F)	8.79
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02650655
Average Temp (°F)	110.98	101.43		
Skin Temperature (°F)	103.69	102.11	U Overall (BTU/hr·ft²·°F)	6.18
Velocity ***	4,243.88	5.52	Effective Area (ft²)	1,053.23
Reynold's Number	990**	33,339	LMTD	9.50
Prandtl Number	0.7280	4.4583	Total Heat Transferred (BTU/hr)	61,863
Bulk Visc (lbm/ft·hr)	0.0469	1.6216		
Skin Visc (lbm/ft·hr)		1.6098	Surface Effectiveness (Eta)	0.9227
Density (lbm/ft³)	0.0657	61.9761	Sensible Heat Transferred (BTU/hr)	61,863
Cp (BTU/lbm·°F)	0.2402	0.9990	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0155	0.3633	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104,770.20	89,504.32	Tube-Side hi (BTU/hr·ft²·°F)	1,522.65
Inlet Temperature (°F)	109.80	100.50	j Factor	0.0070
Outlet Temperature (°F)	107.82	101.08	Air-Side ho (BTU/hr·ft²·°F)	8.78
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02650655
Average Temp (°F)	108.81	100.79		
Skin Temperature (°F)	102.69	101.37	U Overall (BTU/hr·ft²·°F)	6.18
Velocity ***	4,243.88	5.52	Effective Area (ft²)	1,053.23
Reynold's Number	993**	33,114	LMTD	7.97
Prandtl Number	0.7281	4.4918	Total Heat Transferred (BTU/hr)	51,871
Bulk Visc (lbm/ft·hr)	0.0468	1.6326		
Skin Visc (lbm/ft·hr)		1.6226	Surface Effectiveness (Eta)	0.9228
Density (lbm/ft³)	0.0660	61.9842	Sensible Heat Transferred (BTU/hr)	51,871
Cp (BTU/lbm·°F)	0.2402	0.9990	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0154	0.3631	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,770.20	89,504.32
Inlet Temperature (°F)	107.82	100.01
Outlet Temperature (°F)	106.16	100.50
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	106.99	100.26
Skin Temperature (°F)	101.85	100.74
Velocity ***	4,243.88	5.52
Reynold's Number	995**	32,925
Prandtl Number	0.7282	4.5201
Bulk Visc (lbm/ft·hr)	0.0466	1.6419
Skin Visc (lbm/ft·hr)		1.6335
Density (lbm/ft^3)	0.0661	61.9911
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0154	0.3629

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	1,517.83
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	8.77
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.02650655
U Overall (BTU/hr·ft^2·°F)	6.17
Effective Area (ft^2)	1,053.23
LMTD	6.69
Total Heat Transferred (BTU/hr)	43,508
Surface Effectiveness (Eta)	0.9228
Sensible Heat Transferred (BTU/hr)	43,508
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment H to
Proto-Power Calculation
97-199
Revision A

Moist Air Properties

Equations for calculating moist air properties are compiled and/or derived in Proto-Power Calculation 96-069, Reference (1), relying on References (2) and (3) as the principal sources of information. This attachment summarizes the equations pertinent to the moist air conditions calculated for heat exchanger model development. The applicable material has been extracted from Reference (1) leaving equation numbering as it appears in Reference (1) for ease of cross reference.

1. NOMENCLATURE

m_a = Mass of Dry Air, lbm
m_v = Mass of Water Vapor, lbm
P = Atmospheric Pressure, lbf/in^2
P_a = Dry Air Pressure, lbf/in^2
P_s = Saturated Air Pressure, lbf/in^2
P_v = Water Vapor Pressure, lbf/in^2
R_a = Gas constant of Dry Air
R_v = Gas constant of Water Vapor
T = Dry Bulb Temperature, °F
T_w = Wet Bulb Temperature, °F
V = Moist air Volume, ft^3
W = Moist air Specific Humidity
x_v = Mole Fraction of Water Vapor in Moist Air
x_s = Mole Fraction of Water Vapor in Saturated Air
ϕ = Moist Air Relative Humidity
ρ = Moist air Density, lbm/ft^3
ρ_a = Dry Air Density, lbm/ft^3
ρ_v = Water Vapor Density, lbm/ft^3

2. REFERENCES

(1) Proto-Power Calculation 96-069, Fluid Properties - Moist Air - Range 8°F to 300°F, Revision -, dated 12/2/96

(2) Heating Ventilating, and Air Conditioning Analysis and Design, F. C. McQuiston and J. D. Parker, Second Edition, John Wiley & Sons, Inc., 1982

(3) ASHRAE Handbook 1981 Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1982

3. MOIST AIR DENSITY

For dry air:

$$P_a = P - P_v$$ Equation [4]

$$\rho_a = \left(\frac{144}{R_a}\right)\frac{P_a}{(459.67+T)}$$ Equation [5]

where:

R_a = 53.352 (ft-lbf)/(lbm-°R)

For water vapor:

$$\rho_v = \left(\frac{144}{R_v}\right)\frac{P_v}{(459.67+T)}$$ Equation [6]

where:
R_v = 85.778 (ft-lbf)/(lbm-°R)

For moist air:

$$\rho = \rho_a + \rho_v$$ Equation [7]

4. SATURATED WATER VAPOR PRESSURE

$$P_s(T) = a + bT + cT^2 + dT^3 + eT^4 + fT^5$$ Equation [8]

Where;
a = 0.02358607
b = 0.001007276
c = 0.00001888033
d = 0.0000003775047
e = 4.871208E-10
f = 2.109071E-11

5. WATER VAPOR PRESSURE

$$f(T_w) = a + bT_w + cT_w^2 + dT_w^3 + eT_w^4 + fT_w^5$$ Equation [9]

$$P_v(P,T,T_w) = \frac{[(2T_w - T - 2800)f(T_w)] - P(T_w - T)}{(T_w - 2800)}$$ Equation [10]

Where:
a = 0.02358607
b = 0.001007276
c = 0.00001888033
d = 0.0000003775047
e = 4.871208E-10
f = 2.109071E-11

$$P_v = \frac{WR_v P}{R_a + (WR_v)}$$ Equation [11]

6. MOIST AIR SPECIFIC HUMIDITY

$$W = \frac{m_v}{m_a} = \frac{\rho_v}{\rho_a}$$ Equation [12]

Where:

$$m_v = \frac{P_v V}{R_v(459.67 + T)}$$ Equation [13]

$$m_a = \frac{P_a V}{R_a(459.67 + T)}$$ Equation [14]

7. MOIST AIR RELATIVE HUMIDITY

$$\phi = \frac{x_v}{x_s} = \frac{P_v}{P_s}$$ Equation [15]

Moist Air Properties -- Given Dry Bulb and Relative Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	70	°F	
Moist Air Relative Humidity:	RH =	40	%	
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	0.363236046	psia	Equation [8]
Vapor Pressure:	$Pv = RH*Ps$	0.145294418	psia	Equation [15]
Dry Air Pressure:	$Pa = P - Pv =$	14.16970558	psia	Equation [4]
Dry Air Density:	$Rho\ a = (144/53.352)*(Pa/(459.67+T)) =$	0.072204994	lbm/ft^3	Equation [5]
Water Vapor Density:	$Rho\ v = (144/85.778)*(Pv/(459.67+T)) =$	0.000460501	lbm/ft^3	Equation [6]
Moist Air Density:	$Rho = Rho\ a + Rho\ v =$	0.072665495	lbm/ft^3	Equation [7]
Specific Humidity:	$W = Rho\ v / Rho\ a =$	0.006377682		Equation [12]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Coil Specification Condition's

Moist Air Properties -- Given Dry Bulb and Wet Bulb Temperatures *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	150	°F	
Wet Bulb Temperature:	Tw =	92.00	°F	
Wet Bulb Temp. Function:	$F(Tw) = a+(b*Tw)+(c*Tw^2)+(d*Tw^3)+(e*Tw^4)+(f*Tw^5) =$	0.743918919		Equation [9]
Water Vapor Pressure:	$Pv = (((2*Tw-T-2800)*F(Tw))-P*(Tw-T))/(Tw-2800) =$	0.453253224	psia	Equation [10]
Dry Air Pressure:	Pa =P - Pv =	13.86174678	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.061367004	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001248052	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.062615056	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	3.721743953	psia	Equation [8]
Moist Air Specific Humidity:	W = Rho v / Rho a =	0.020337508		Equation [12]
Moist Air Relative Humidity:	RH = Pv /Ps =	12.17852	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Coil Benchmark Conditions

Moist Air Properties -- Given Dry Bulb and Wet Bulb Temperatures*

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	148	°F	
Wet Bulb Temperature:	Tw =	91.60	°F	
Wet Bulb Temp. Function:	$F(Tw) = a+(b*Tw)+(c*Tw^2)+(d*Tw^3)+(e*Tw^4)+(f*Tw^5) =$	0.734713202		Equation [9]
Water Vapor Pressure:	Pv = (((2*Tw-T-2800)*F(Tw))-P*(Tw-T))/(Tw-2800) =	0.451915914	psia	Equation [10]
Dry Air Pressure:	Pa =P - Pv =	13.86308409	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.061574919	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001248465	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.062823384	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	3.541336347	psia	Equation [8]
Moist Air Specific Humidity:	W = Rho v / Rho a =	0.020275546		Equation [12]
Moist Air Relative Humidity:	RH = Pv /Ps =	12.76117	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

*LaSalle Station: Reference Conditions

Moist Air Properties -- Given Dry Bulb and Relative Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	148	°F	
Moist Air Relative Humidity:	RH =	12.76	%	
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	3.541336347	psia	Equation [8]
Vapor Pressure:	Pv = RH*Ps	0.451874518	psia	Equation [15]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.061575103	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001248351	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.062823454	lbm/ft^3	Equation [7]
Specific Humidity:	W = Rho v / Rho a =	0.020273629		Equation [12]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* LaSalle Station Reference Conditions (RH = 12.76%)

Moist Air Properties -- Given Dry Bulb and Specific Humidity*

Total Pressure:	$P =$	14.315	psia	
Dry Bulb Temperature:	$T =$	104.31	°F	Inlet Air Flow 28445.13627
Specific Humidity:	$W =$	0.020273629		
Water Vapor Pressure:	$Pv = (W*Rv*P)/(Ra+(W*Rv)) =$	0.451874518	psia	Equation [11]
Dry Air Pressure:	$Pa = P - Pv =$	13.86312548	psia	Equation [4]
Dry Air Density:	$Rho\ a = (144/53.352)*(Pa/(459.67+T)) =$	0.066345159	lbm/ft^3	Equation [5]
Water Vapor Density:	$Rho\ v = (144/85.778)*(Pv/(459.67+T)) =$	0.001345057	lbm/ft^3	Equation [6]
Moist Air Density:	$Rho = Rho\ a + Rho\ v =$	0.067690216	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.080650628	psia	Equation [8]
Moist Air Relative Humidity:	$RH = Pv / Ps =$	41.81504238	%	Equation [15]
Equation Coefficients:	$a =$	2.358607E-02		
	$b =$	1.007276E-03		
	$c =$	1.888033E-05		
	$d =$	3.775047E-07		
	$e =$	4.871208E-10		
	$f =$	2.109071E-11		

* Coil Outlet Conditions (Clean)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	Inlet Air Flow
Dry Bulb Temperature:	T =	106.16	°F	28352.13395
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.066128241	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001340659	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.067468901	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.14119985	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	39.59644034	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

*Coil Outlet Condition (Service)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	106.85	°F	Inlet Air Flow 28317.60212
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.0660477	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001339027	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.067386726	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.164520875	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	38.80347081	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Coil Outlet Conditions - Limiting Flow Analysis (180 gpm Case)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	111.85	°F	Inlet Air Flow 28069.86274
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.065469875	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001327312	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.066797187	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.34613727	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	33.56823468	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Coil Outlet Conditions – Limiting Flow Analysis (72.5 gpm Case)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	112.24	°F	Inlet Air Flow 28050.72119
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.065425229	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001326407	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.066751636	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b^{*}T)+(c^{*}T^{2})+(d^{*}T^{3})+(e^{*}T^{4})+(f^{*}T^{5}) =$	1.361275803	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	33.19492765	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Coil Outlet Conditions (Reduced Finned Length @ 72.5 gpm)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	109.52	°F	Inlet Air Flow 28184.76775
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.065737878	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001332745	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.067070623	lbm/ft^3	Equation [7]
Saturated Air Pressure:	Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =	1.258679377	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	35.90068496	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Coil Outlet Conditions (72.5 gpm Tube f=0.0000)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	110.72	°F	Inlet Air Flow 28125.47196
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	$Pv = (W*Rv*P)/(Ra+(W*Rv)) =$	0.451874518	psia	Equation [11]
Dry Air Pressure:	$Pa = P - Pv =$	13.86312548	psia	Equation [4]
Dry Air Density:	$Rho\ a = (144/53.352)*(Pa/(459.67+T)) =$	0.065599577	lbm/ft^3	Equation [5]
Water Vapor Density:	$Rho\ v = (144/85.778)*(Pv/(459.67+T)) =$	0.001329941	lbm/ft^3	Equation [6]
Moist Air Density:	$Rho = Rho\ a + Rho\ v =$	0.066929518	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.303089954	psia	Equation [8]
Moist Air Relative Humidity:	$RH = Pv / Ps =$	34.6771546	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Coil Outlet Conditions (72.5 gpm Tube f = 0.0010)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	Inlet Air Flow
Dry Bulb Temperature:	T =	111.85	°F	28069.86274
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.065469875	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001327312	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.066797187	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.34613727	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	33.56823468	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Coil Outlet Conditions (72.5 gpm Tube f=0.0020)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	112.97	°F	Inlet Air Flow 28014.9622
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.065341825	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001324716	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.066666541	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.390006231	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	32.50881239	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Coil Outlet Conditions (72.5 gpm Tube f = 0.0030)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	113.96	°F	Inlet Air Flow 27966.61254
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.065229055	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.00132243	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.066551484	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.429802188	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	31.60398842	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Coil Outlet Conditions (72.5 gpm Tube f = 0.0040)

Attachment I to
Proto-Power Calculation
97-199
Revision A

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water	
Tube Fouling Factor	0.002000	←
Air-Side Fouling	0.002000	←
Design Heat Transfer (BTU/hr)	1,108,000	
Atmospheric Pressure	14.315	
Sensible Heat Ratio	1.00	
Performance Factor (% Reduction)	0.000	
Heat Exchanger Type	Counter Flow	
Fin Type	Circular Fins	
Fin Configuration	LaSalle Cooler 1(2)VY03A	
	j = EXP[-2.5939 + -0.3438 * LOG(Re)]	
Coil Finned Length (in)	108.000	←
Fin Pitch (Fins/Inch)	10.000	
Fin Conductivity (BTU/hr·ft·°F)	128.000	
Fin Tip Thickness (inches)	0.0120	
Fin Root Thickness (inches)	0.0120	
Circular Fin Height (inches)	1.452	
Number of Coils Per Unit	2	
Number of Tube Rows	10	
Number of Tubes Per Row	24.00	
Active Tubes Per Row	24.00	
Tube Inside Diameter (in)	0.5270	
Tube Outside Diameter (in)	0.6250	
Longitudinal Tube Pitch (in)	1.400	
Transverse Tube Pitch (in)	1.410	
Number of Serpentines	1.000	
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00	

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	180.00
Air Flow (acfm)	28,318.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

ComEd -- LaSalle

Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Limiting Flow Analysis -- 180 gpm Case

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104,644.56	89,504.32	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	106.85	112.00	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	10,532.34
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	1,077,246
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	1,077,246
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104,644.56	89,504.32	Tube-Side hi (BTU/hr·ft²·°F)	1,612.69
Inlet Temperature (°F)	148.00	109.71	j Factor	0.0071
Outlet Temperature (°F)	140.18	112.00	Air-Side ho (BTU/hr·ft²·°F)	8.93
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	144.09	110.86		
Skin Temperature (°F)	120.35	113.00	U Overall (BTU/hr·ft²·°F)	5.88
Velocity ***	4,238.79	5.53	Effective Area (ft²)	1,053.23
Reynold's Number	946**	36,742	LMTD	33.07
Prandtl Number	0.7255	4.0060	Total Heat Transferred (BTU/hr)	204,818
Bulk Visc (lbm/ft·hr)	0.0490	1.4714		
Skin Visc (lbm/ft·hr)		1.4404	Surface Effectiveness (Eta)	0.9215
Density (lbm/ft³)	0.0624	61.8479	Sensible Heat Transferred (BTU/hr)	204,818
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0162	0.3668	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Limiting Flow Analysis -- 180 gpm Case

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,644.56	89,504.32
Inlet Temperature (°F)	140.18	107.78
Outlet Temperature (°F)	133.57	109.71
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	136.87	108.74
Skin Temperature (°F)	116.78	110.57
Velocity ***	4,238.79	5.53
Reynold's Number	955**	35,970
Prandtl Number	0.7261	4.1007
Bulk Visc (lbm/ft·hr)	0.0485	1.5030
Skin Visc (lbm/ft·hr)		1.4755
Density (lbm/ft³)	0.0631	61.8777
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3661

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	1,593.93
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.90
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.86
Effective Area (ft²)	1,053.23
LMTD	28.00
Total Heat Transferred (BTU/hr)	172,828
Surface Effectiveness (Eta)	0.9218
Sensible Heat Transferred (BTU/hr)	172,828
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,644.56	89,504.32
Inlet Temperature (°F)	133.57	106.14
Outlet Temperature (°F)	128.00	107.78
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	130.79	106.96
Skin Temperature (°F)	113.76	108.52
Velocity ***	4,238.79	5.52
Reynold's Number	963**	35,322
Prandtl Number	0.7266	4.1835
Bulk Visc (lbm/ft·hr)	0.0482	1.5305
Skin Visc (lbm/ft·hr)		1.5064
Density (lbm/ft³)	0.0637	61.9024
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3654

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	1,578.04
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.87
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.85
Effective Area (ft²)	1,053.23
LMTD	23.71
Total Heat Transferred (BTU/hr)	145,975
Surface Effectiveness (Eta)	0.9220
Sensible Heat Transferred (BTU/hr)	145,975
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,644.56	89,504.32
Inlet Temperature (°F)	128.00	104.76
Outlet Temperature (°F)	123.28	106.14
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	125.64	105.45
Skin Temperature (°F)	111.21	106.78
Velocity ***	4,238.79	5.52
Reynold's Number	969**	34,778
Prandtl Number	0.7270	4.2556
Bulk Visc (lbm/ft·hr)	0.0478	1.5545
Skin Visc (lbm/ft·hr)		1.5333
Density (lbm/ft³)	0.0642	61.9229
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0158	0.3649

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	1,564.58
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.85
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.83
Effective Area (ft²)	1,053.23
LMTD	20.09
Total Heat Transferred (BTU/hr)	123,397
Surface Effectiveness (Eta)	0.9222
Sensible Heat Transferred (BTU/hr)	123,397
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,644.56	89,504.32
Inlet Temperature (°F)	123.28	103.60
Outlet Temperature (°F)	119.30	104.76
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	121.29	104.18
Skin Temperature (°F)	109.06	105.31
Velocity ***	4,238.79	5.52
Reynold's Number	975**	34,320
Prandtl Number	0.7273	4.3181
Bulk Visc (lbm/ft·hr)	0.0476	1.5752
Skin Visc (lbm/ft·hr)		1.5567
Density (lbm/ft³)	0.0646	61.9400
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3644

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	1,553.17
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.83
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.82
Effective Area (ft²)	1,053.23
LMTD	17.03
Total Heat Transferred (BTU/hr)	104,384
Surface Effectiveness (Eta)	0.9224
Sensible Heat Transferred (BTU/hr)	104,384
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104,644.56	89,504.32	Tube-Side hi (BTU/hr·ft^2·°F)	1,543.49
Inlet Temperature (°F)	119.30	102.61	j Factor	0.0070
Outlet Temperature (°F)	115.92	103.60	Air-Side ho (BTU/hr·ft^2·°F)	8.81
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
Average Temp (°F)	117.61	103.10		
Skin Temperature (°F)	107.24	104.07	U Overall (BTU/hr·ft^2·°F)	5.81
Velocity ***	4,238.79	5.52	Effective Area (ft^2)	1,053.23
Reynold's Number	980**	33,935	LMTD	14.44
Prandtl Number	0.7276	4.3722	Total Heat Transferred (BTU/hr)	88,354
Bulk Visc (lbm/ft·hr)	0.0473	1.5931		
Skin Visc (lbm/ft·hr)		1.5770	Surface Effectiveness (Eta)	0.9225
Density (lbm/ft^3)	0.0650	61.9543	Sensible Heat Transferred (BTU/hr)	88,354
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3640	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104,644.56	89,504.32	Tube-Side hi (BTU/hr·ft^2·°F)	1,535.29
Inlet Temperature (°F)	115.92	101.77	j Factor	0.0070
Outlet Temperature (°F)	113.06	102.61	Air-Side ho (BTU/hr·ft^2·°F)	8.80
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
Average Temp (°F)	114.49	102.19		
Skin Temperature (°F)	105.70	103.01	U Overall (BTU/hr·ft^2·°F)	5.80
Velocity ***	4,238.79	5.52	Effective Area (ft^2)	1,053.23
Reynold's Number	984**	33,609	LMTD	12.24
Prandtl Number	0.7278	4.4188	Total Heat Transferred (BTU/hr)	74,823
Bulk Visc (lbm/ft·hr)	0.0471	1.6085		
Skin Visc (lbm/ft·hr)		1.5946	Surface Effectiveness (Eta)	0.9226
Density (lbm/ft^3)	0.0653	61.9662	Sensible Heat Transferred (BTU/hr)	74,823
Cp (BTU/lbm·°F)	0.2402	0.9990	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3636	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,644.56	89,504.32
Inlet Temperature (°F)	113.06	101.06
Outlet Temperature (°F)	110.64	101.77
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	111.85	101.42
Skin Temperature (°F)	104.39	102.11
Velocity ***	4,238.79	5.52
Reynold's Number	987**	33,335
Prandtl Number	0.7279	4.4589
Bulk Visc (lbm/ft·hr)	0.0470	1.6218
Skin Visc (lbm/ft·hr)		1.6098
Density (lbm/ft³)	0.0656	61.9762
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0155	0.3633

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	1,528.33
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.78
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.79
Effective Area (ft²)	1,053.23
LMTD	10.39
Total Heat Transferred (BTU/hr)	63,392
Surface Effectiveness (Eta)	0.9227
Sensible Heat Transferred (BTU/hr)	63,392
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,644.56	89,504.32
Inlet Temperature (°F)	110.64	100.46
Outlet Temperature (°F)	108.59	101.06
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	109.61	100.76
Skin Temperature (°F)	103.28	101.36
Velocity ***	4,238.79	5.52
Reynold's Number	990**	33,103
Prandtl Number	0.7281	4.4934
Bulk Visc (lbm/ft·hr)	0.0468	1.6331
Skin Visc (lbm/ft·hr)		1.6228
Density (lbm/ft³)	0.0659	61.9846
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0154	0.3631

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	1,522.43
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.77
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.79
Effective Area (ft²)	1,053.23
LMTD	8.81
Total Heat Transferred (BTU/hr)	53,727
Surface Effectiveness (Eta)	0.9228
Sensible Heat Transferred (BTU/hr)	53,727
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,644.56	89,504.32
Inlet Temperature (°F)	108.59	99.95
Outlet Temperature (°F)	106.85	100.46
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	107.72	100.21
Skin Temperature (°F)	102.35	100.71
Velocity ***	4,238.79	5.52
Reynold's Number	993**	32,906
Prandtl Number	0.7282	4.5229
Bulk Visc (lbm/ft·hr)	0.0467	1.6429
Skin Visc (lbm/ft·hr)		1.6340
Density (lbm/ft³)	0.0661	61.9917
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0154	0.3629

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	1,517.42
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.77
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.78
Effective Area (ft²)	1,053.23
LMTD	7.48
Total Heat Transferred (BTU/hr)	45,549
Surface Effectiveness (Eta)	0.9229
Sensible Heat Transferred (BTU/hr)	45,549
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
Limiting Flow Analysis -- 72.5 gpm Case

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.002000 ←
Air-Side Fouling	0.002000 ←
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000 ←
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	28,070.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Limiting Flow Analysis -- 72.5 gpm Case

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,728.12	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	111.85	126.02	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	10,532.34
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	938,124
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	938,124
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,728.12	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	834.45
Inlet Temperature (°F)	148.00	122.59	j Factor	0.0071
Outlet Temperature (°F)	143.24	126.02	Air-Side ho (BTU/hr·ft²·°F)	8.89
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	145.62	124.30		
Skin Temperature (°F)	131.24	126.80	U Overall (BTU/hr·ft²·°F)	5.53
Velocity ***	4,201.67	2.23	Effective Area (ft²)	1,053.23
Reynold's Number	936**	16,832	LMTD	21.19
Prandtl Number	0.7253	3.4788	Total Heat Transferred (BTU/hr)	123,422
Bulk Visc (lbm/ft·hr)	0.0491	1.2936		
Skin Visc (lbm/ft·hr)		1.2646	Surface Effectiveness (Eta)	0.9219
Density (lbm/ft³)	0.0621	61.6438	Sensible Heat Transferred (BTU/hr)	123,422
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3714	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	103,728.12	36,050.35
Inlet Temperature (°F)	143.24	119.38
Outlet Temperature (°F)	138.79	122.59
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	141.02	120.98
Skin Temperature (°F)	127.51	123.36
Velocity ***	4,201.67	2.23
Reynold's Number	942**	16,322
Prandtl Number	0.7258	3.5979
Bulk Visc (lbm/ft·hr)	0.0488	1.3341
Skin Visc (lbm/ft·hr)		1.3049
Density (lbm/ft³)	0.0625	61.6964
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3704

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	820.85
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.87
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.51
Effective Area (ft²)	1,053.23
LMTD	19.91
Total Heat Transferred (BTU/hr)	115,582
Surface Effectiveness (Eta)	0.9220
Sensible Heat Transferred (BTU/hr)	115,582
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	103,728.12	36,050.35
Inlet Temperature (°F)	138.79	116.37
Outlet Temperature (°F)	134.62	119.38
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	136.70	117.87
Skin Temperature (°F)	124.03	120.14
Velocity ***	4,201.67	2.23
Reynold's Number	947**	15,849
Prandtl Number	0.7261	3.7157
Bulk Visc (lbm/ft·hr)	0.0485	1.3739
Skin Visc (lbm/ft·hr)		1.3447
Density (lbm/ft³)	0.0630	61.7443
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3693

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	808.06
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.85
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.49
Effective Area (ft²)	1,053.23
LMTD	18.72
Total Heat Transferred (BTU/hr)	108,279
Surface Effectiveness (Eta)	0.9222
Sensible Heat Transferred (BTU/hr)	108,279
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,728.12	36,050.35
Inlet Temperature (°F)	134.62	113.55
Outlet Temperature (°F)	130.71	116.37
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	132.66	114.96
Skin Temperature (°F)	120.76	117.11
Velocity ***	4,201.67	2.23
Reynold's Number	952**	15,410
Prandtl Number	0.7265	3.8319
Bulk Visc (lbm/ft·hr)	0.0483	1.4130
Skin Visc (lbm/ft·hr)		1.3839
Density (lbm/ft³)	0.0634	61.7881
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3683

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	796.02
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.83
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.48
Effective Area (ft²)	1,053.23
LMTD	17.59
Total Heat Transferred (BTU/hr)	101,473
Surface Effectiveness (Eta)	0.9224
Sensible Heat Transferred (BTU/hr)	101,473
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,728.12	36,050.35
Inlet Temperature (°F)	130.71	110.91
Outlet Temperature (°F)	127.04	113.55
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	128.87	112.23
Skin Temperature (°F)	117.70	114.28
Velocity ***	4,201.67	2.23
Reynold's Number	957**	15,003
Prandtl Number	0.7268	3.9463
Bulk Visc (lbm/ft·hr)	0.0480	1.4514
Skin Visc (lbm/ft·hr)		1.4224
Density (lbm/ft³)	0.0638	61.8281
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3673

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	784.69
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.81
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.46
Effective Area (ft²)	1,053.23
LMTD	16.54
Total Heat Transferred (BTU/hr)	95,126
Surface Effectiveness (Eta)	0.9225
Sensible Heat Transferred (BTU/hr)	95,126
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,728.12	36,050.35
Inlet Temperature (°F)	127.04	108.43
Outlet Temperature (°F)	123.60	110.91
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	125.32	109.67
Skin Temperature (°F)	114.82	111.62
Velocity ***	4,201.67	2.23
Reynold's Number	961**	14,624
Prandtl Number	0.7270	4.0586
Bulk Visc (lbm/ft·hr)	0.0478	1.4889
Skin Visc (lbm/ft·hr)		1.4602
Density (lbm/ft^3)	0.0642	61.8646
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3664

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	774.02
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	8.80
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
U Overall (BTU/hr·ft^2·°F)	5.44
Effective Area (ft^2)	1,053.23
LMTD	15.56
Total Heat Transferred (BTU/hr)	89,203
Surface Effectiveness (Eta)	0.9226
Sensible Heat Transferred (BTU/hr)	89,203
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,728.12	36,050.35
Inlet Temperature (°F)	123.60	106.11
Outlet Temperature (°F)	120.38	108.43
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	121.99	107.27
Skin Temperature (°F)	112.13	109.12
Velocity ***	4,201.67	2.23
Reynold's Number	965**	14,272
Prandtl Number	0.7273	4.1689
Bulk Visc (lbm/ft·hr)	0.0476	1.5256
Skin Visc (lbm/ft·hr)		1.4972
Density (lbm/ft^3)	0.0645	61.8981
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3655

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	763.98
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	8.78
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
U Overall (BTU/hr·ft^2·°F)	5.43
Effective Area (ft^2)	1,053.23
LMTD	14.63
Total Heat Transferred (BTU/hr)	83,674
Surface Effectiveness (Eta)	0.9227
Sensible Heat Transferred (BTU/hr)	83,674
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,728.12	36,050.35
Inlet Temperature (°F)	120.38	103.93
Outlet Temperature (°F)	117.35	106.11
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	118.86	105.02
Skin Temperature (°F)	109.60	106.78
Velocity ***	4,201.67	2.22
Reynold's Number	969**	13,945
Prandtl Number	0.7275	4.2767
Bulk Visc (lbm/ft·hr)	0.0474	1.5615
Skin Visc (lbm/ft·hr)		1.5334
Density (lbm/ft³)	0.0649	61.9287
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3647

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	754.53
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.77
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.42
Effective Area (ft²)	1,053.23
LMTD	13.77
Total Heat Transferred (BTU/hr)	78,509
Surface Effectiveness (Eta)	0.9229
Sensible Heat Transferred (BTU/hr)	78,509
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,728.12	36,050.35
Inlet Temperature (°F)	117.35	101.88
Outlet Temperature (°F)	114.51	103.93
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	115.93	102.91
Skin Temperature (°F)	107.22	104.57
Velocity ***	4,201.67	2.22
Reynold's Number	973**	13,640
Prandtl Number	0.7277	4.3821
Bulk Visc (lbm/ft·hr)	0.0472	1.5964
Skin Visc (lbm/ft·hr)		1.5687
Density (lbm/ft³)	0.0652	61.9568
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0156	0.3639

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	745.64
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.75
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.40
Effective Area (ft²)	1,053.23
LMTD	12.95
Total Heat Transferred (BTU/hr)	73,683
Surface Effectiveness (Eta)	0.9230
Sensible Heat Transferred (BTU/hr)	73,683
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,728.12	36,050.35
Inlet Temperature (°F)	114.51	99.96
Outlet Temperature (°F)	111.85	101.88
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	113.18	100.92
Skin Temperature (°F)	104.99	102.51
Velocity ***	4,201.67	2.22
Reynold's Number	977**	13,356
Prandtl Number	0.7278	4.4848
Bulk Visc (lbm/ft·hr)	0.0470	1.6303
Skin Visc (lbm/ft·hr)		1.6031
Density (lbm/ft^{3})	0.0655	61.9826
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0155	0.3631

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^{2}·°F)	737.27
j Factor	0.0070
Air-Side ho (BTU/hr·ft^{2}·°F)	8.74
Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00029413
Overall Fouling (hr·ft^{2}·°F/BTU)	0.03734207
U Overall (BTU/hr·ft^{2}·°F)	5.39
Effective Area (ft^{2})	1,053.23
LMTD	12.19
Total Heat Transferred (BTU/hr)	69,171
Surface Effectiveness (Eta)	0.9231
Sensible Heat Transferred (BTU/hr)	69,171
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^{2}), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Limiting Flow @Reduced Finned Length

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.002000
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	102.750 ← *
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Limiting Flow @Reduced Finned Length

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	28,051.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Limiting Flow @Reduced Finned Length

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,657.91	36,050.35	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	112.24	125.78	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	10,020.35
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	927,356
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	927,356
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,657.91	36,050.35	Tube-Side hi (BTU/hr·ft^2·°F)	833.71
Inlet Temperature (°F)	148.00	122.42	j Factor	0.0070
Outlet Temperature (°F)	143.33	125.78	Air-Side ho (BTU/hr·ft^2·°F)	9.18
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
Average Temp (°F)	145.66	124.10		
Skin Temperature (°F)	131.25	126.68	U Overall (BTU/hr·ft^2·°F)	5.64
Velocity ***	4,413.36	2.23	Effective Area (ft^2)	1,002.04
Reynold's Number	983**	16,800	LMTD	21.44
Prandtl Number	0.7253	3.4859	Total Heat Transferred (BTU/hr)	121,197
Bulk Visc (lbm/ft·hr)	0.0491	1.2961		
Skin Visc (lbm/ft·hr)		1.2660	Surface Effectiveness (Eta)	0.9196
Density (lbm/ft^3)	0.0621	61.6471	Sensible Heat Transferred (BTU/hr)	121,197
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3714	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,657.91	36,050.35
Inlet Temperature (°F)	143.33	119.26
Outlet Temperature (°F)	138.94	122.42
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	141.13	120.84
Skin Temperature (°F)	127.59	123.29
Velocity ***	4,413.36	2.23
Reynold's Number	989**	16,300
Prandtl Number	0.7257	3.6033
Bulk Visc (lbm/ft·hr)	0.0488	1.3359
Skin Visc (lbm/ft·hr)		1.3057
Density (lbm/ft^3)	0.0625	61.6987
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3703

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	820.34
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	9.16
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
U Overall (BTU/hr·ft^2·°F)	5.62
Effective Area (ft^2)	1,002.04
LMTD	20.18
Total Heat Transferred (BTU/hr)	113,692
Surface Effectiveness (Eta)	0.9197
Sensible Heat Transferred (BTU/hr)	113,692
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,657.91	36,050.35
Inlet Temperature (°F)	138.94	116.30
Outlet Temperature (°F)	134.83	119.26
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	136.88	117.78
Skin Temperature (°F)	124.15	120.12
Velocity ***	4,413.36	2.23
Reynold's Number	994**	15,834
Prandtl Number	0.7261	3.7195
Bulk Visc (lbm/ft·hr)	0.0485	1.3752
Skin Visc (lbm/ft·hr)		1.3449
Density (lbm/ft^3)	0.0630	61.7458
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3693

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	807.75
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	9.14
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
U Overall (BTU/hr·ft^2·°F)	5.60
Effective Area (ft^2)	1,002.04
LMTD	19.00
Total Heat Transferred (BTU/hr)	106,688
Surface Effectiveness (Eta)	0.9199
Sensible Heat Transferred (BTU/hr)	106,688
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,657.91	36,050.35
Inlet Temperature (°F)	134.83	113.51
Outlet Temperature (°F)	130.97	116.30
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	132.90	114.90
Skin Temperature (°F)	120.92	117.14
Velocity ***	4,413.36	2.23
Reynold's Number	1,000**	15,402
Prandtl Number	0.7264	3.8342
Bulk Visc (lbm/ft·hr)	0.0483	1.4138
Skin Visc (lbm/ft·hr)		1.3836
Density (lbm/ft^3)	0.0634	61.7889
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3683

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft^2·°F)	795.87
j Factor	0.0070
Air-Side ho (BTU/hr·ft^2·°F)	9.12
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
U Overall (BTU/hr·ft^2·°F)	5.59
Effective Area (ft^2)	1,002.04
LMTD	17.89
Total Heat Transferred (BTU/hr)	100,150
Surface Effectiveness (Eta)	0.9201
Sensible Heat Transferred (BTU/hr)	100,150
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,657.91	36,050.35
Inlet Temperature (°F)	130.97	110.90
Outlet Temperature (°F)	127.34	113.51
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	129.15	112.21
Skin Temperature (°F)	117.88	114.33
Velocity ***	4,413.36	2.23
Reynold's Number	1,004	14,999
Prandtl Number	0.7267	3.9473
Bulk Visc (lbm/ft·hr)	0.0481	1.4517
Skin Visc (lbm/ft·hr)		1.4217
Density (lbm/ft^3)	0.0638	61.8284
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3673

Tube-Side hi (BTU/hr·ft^2·°F)	784.67
j Factor	0.0069
Air-Side ho (BTU/hr·ft^2·°F)	9.10
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
U Overall (BTU/hr·ft^2·°F)	5.57
Effective Area (ft^2)	1,002.04
LMTD	16.85
Total Heat Transferred (BTU/hr)	94,041
Surface Effectiveness (Eta)	0.9202
Sensible Heat Transferred (BTU/hr)	94,041
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,657.91	36,050.35	Tube-Side hi (BTU/hr·ft^2·°F)	774.12
Inlet Temperature (°F)	127.34	108.45	j Factor	0.0069
Outlet Temperature (°F)	123.93	110.90	Air-Side ho (BTU/hr·ft^2·°F)	9.09
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
Average Temp (°F)	125.64	109.67		
Skin Temperature (°F)	115.03	111.70	U Overall (BTU/hr·ft^2·°F)	5.55
Velocity ***	4,413.36	2.23	Effective Area (ft^2)	1,002.04
Reynold's Number	1,009	14,625	LMTD	15.87
Prandtl Number	0.7270	4.0585	Total Heat Transferred (BTU/hr)	88,332
Bulk Visc (lbm/ft·hr)	0.0478	1.4889		
Skin Visc (lbm/ft·hr)		1.4590	Surface Effectiveness (Eta)	0.9203
Density (lbm/ft^3)	0.0641	61.8646	Sensible Heat Transferred (BTU/hr)	88,332
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0158	0.3664	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,657.91	36,050.35	Tube-Side hi (BTU/hr·ft^2·°F)	764.17
Inlet Temperature (°F)	123.93	106.14	j Factor	0.0069
Outlet Temperature (°F)	120.73	108.45	Air-Side ho (BTU/hr·ft^2·°F)	9.07
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
Average Temp (°F)	122.33	107.30		
Skin Temperature (°F)	112.36	109.22	U Overall (BTU/hr·ft^2·°F)	5.54
Velocity ***	4,413.36	2.23	Effective Area (ft^2)	1,002.04
Reynold's Number	1,014	14,276	LMTD	14.95
Prandtl Number	0.7272	4.1677	Total Heat Transferred (BTU/hr)	82,993
Bulk Visc (lbm/ft·hr)	0.0476	1.5253		
Skin Visc (lbm/ft·hr)		1.4957	Surface Effectiveness (Eta)	0.9205
Density (lbm/ft^3)	0.0645	61.8978	Sensible Heat Transferred (BTU/hr)	82,993
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0157	0.3656	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,657.91	36,050.35
Inlet Temperature (°F)	120.73	103.98
Outlet Temperature (°F)	117.72	106.14
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	119.23	105.06
Skin Temperature (°F)	109.84	106.89
Velocity ***	4,413.36	2.22
Reynold's Number	1,018	13,951
Prandtl Number	0.7275	4.2747
Bulk Visc (lbm/ft·hr)	0.0474	1.5608
Skin Visc (lbm/ft·hr)		1.5316
Density (lbm/ft^3)	0.0648	61.9282
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3647

Tube-Side hi (BTU/hr·ft^2·°F)	754.79
j Factor	0.0069
Air-Side ho (BTU/hr·ft^2·°F)	9.06
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
U Overall (BTU/hr·ft^2·°F)	5.52
Effective Area (ft^2)	1,002.04
LMTD	14.09
Total Heat Transferred (BTU/hr)	77,998
Surface Effectiveness (Eta)	0.9206
Sensible Heat Transferred (BTU/hr)	77,998
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,657.91	36,050.35
Inlet Temperature (°F)	117.72	101.94
Outlet Temperature (°F)	114.90	103.98
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	116.31	102.96
Skin Temperature (°F)	107.47	104.70
Velocity ***	4,413.36	2.22
Reynold's Number	1,022	13,648
Prandtl Number	0.7277	4.3794
Bulk Visc (lbm/ft·hr)	0.0472	1.5955
Skin Visc (lbm/ft·hr)		1.5666
Density (lbm/ft^3)	0.0651	61.9561
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3639

Tube-Side hi (BTU/hr·ft^2·°F)	745.95
j Factor	0.0069
Air-Side ho (BTU/hr·ft^2·°F)	9.04
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
U Overall (BTU/hr·ft^2·°F)	5.51
Effective Area (ft^2)	1,002.04
LMTD	13.28
Total Heat Transferred (BTU/hr)	73,322
Surface Effectiveness (Eta)	0.9207
Sensible Heat Transferred (BTU/hr)	73,322
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 10(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	103,657.91	36,050.35
Inlet Temperature (°F)	114.90	100.03
Outlet Temperature (°F)	112.24	101.94
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	113.57	100.98
Skin Temperature (°F)	105.25	102.64
Velocity ***	4,413.36	2.22
Reynold's Number	1,026	13,365
Prandtl Number	0.7278	4.4816
Bulk Visc (lbm/ft·hr)	0.0471	1.6292
Skin Visc (lbm/ft·hr)		1.6008
Density (lbm/ft³)	0.0654	61.9818
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0155	0.3632

Tube-Side hi (BTU/hr·ft²·°F)	737.61
j Factor	0.0069
Air-Side ho (BTU/hr·ft²·°F)	9.03
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.50
Effective Area (ft²)	1,002.04
LMTD	12.51
Total Heat Transferred (BTU/hr)	68,944
Surface Effectiveness (Eta)	0.9208
Sensible Heat Transferred (BTU/hr)	68,944
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment J to
Proto-Power Calculation
97-199
Revision A

Proto-HX Analytical Uncertainty Calculation
[Circular Fin Air Coil Application]

Purpose

The purpose of the following calculation is to evaluate the analytical uncertainty associated with the analysis of test data and the computation of heat transfer rate at a given extrapolation condition. This calculation focuses only on the parameters that are not measured during the thermal performance test but factor into the analysis of the test results. Test parameter measurement uncertainty is treated separately in the test uncertainty analysis. The calculation of analytical uncertainty is derived for a typical Air Cooler with "n" tube rows.

Governing Heat Transfer Equations

Heat transfer calculations associated with a heat exchanger generally reduce to satisfying the following equations:

1) $q = U\, A_o\, LMTD$

Where:

q = Heat transfer rate at test conditions (BTU/hr)
U = Overall heat transfer coefficient at test conditions (BTU/hr-°F-ft^2)
A_o = Heat transfer surface area referenced to outside (air-side) surface (ft^2)
LMTD = Log Mean Temperature Difference at test conditions (°F)

and

2) $q = \dot{m} c_p (T_{c_o} - T_{c_i}) = \rho Q c_p \Delta T$

Where:

q = Heat transfer rate at test conditions (BTU/hr)
$\dot{m}$ = Mass flow rate at test conditions (lbm/hr)
c_p = Specific heat of cooling water at test conditions (Btu/lb$_m$-°F)
T_{ci} = Tube-side inlet temperature at test conditions (°F)
T_{co} = Tube-side outlet temperature at test conditions (°F)
ρ = Density of tube-side fluid at average bulk temperature at test conditions (lb$_m$/ft^3)
Q = Volumetric flow rate of tube-side fluid at test conditions (gpm)

The first equation is used, in Proto-HX, to evaluate the heat transfer rate from test data. The analytical uncertainties associated with evaluating the fluid properties are usually the only contributors to the overall uncertainty when using this equation. For a given test condition, the right hand side of the second equation is evaluated such that it matches the measured heat transfer rate, "q". In Proto-HX, this means iterating on fouling factor, and therefore "U", until the heat transfer equation is satisfied.

The following equations are used for this iteration:

3) $$R = \frac{1}{U} = \frac{A_o \text{ LMTD}_{Test}}{q_{Test}}$$

Where:

R = Overall heat transfer thermal resistance at test conditions (hr-°F-ft^2/ BTU)
U = Overall heat transfer coefficient at test conditions (BTU/hr-°F-ft^2)
A_o = Outside heat transfer surface area (ft^2)
LMTD = Log Mean Temperature Difference at test conditions (°F)
q = Heat transfer rate at test conditions (BTU/hr)

and

4) $$R_f = R - \frac{1}{h_o \eta_s} - R_w - \left(\frac{A_o}{A_i}\right)\frac{1}{h_i}$$

Where:

R_f = Fouling resistance (hr-°F-ft^2/ BTU)
R = Overall heat transfer thermal resistance at test conditions (hr-°F-ft^2/ BTU)
h_o = Outside convection film coefficient at test conditions (BTU/hr-°F-ft^2)
η_s = Fin surface effectiveness
R_w = Wall thermal resistance at test conditions (hr-°F-ft^2/ BTU)
A_o = Outside heat transfer surface area (ft^2)
A_i = Inside heat transfer surface area (ft^2)
h_i = Inside convection film coefficient at test conditions (BTU/hr-°F-ft^2)

These same equations must be satisfied when evaluating the capacity of a heat exchanger at a given fouling condition (i.e., when extrapolating to the limiting thermal condition). The following equations are used for the extrapolation process:

5) $$R^* = R_f + \frac{1}{h_o * \eta_s} + R_w^* + \left(\frac{A_o}{A_i}\right)\frac{1}{h_i *}$$

Where:

R^* = Overall thermal resistance at extrapolation conditions (hr-°F-ft^2/ BTU)
R_f = Calculated fouling resistance (hr-°F-ft^2/ BTU)
h_{o*} = Outside convection film coefficient at extrapolation conditions (BTU/hr-°F-ft^2)
η_s = Fin surface effectiveness
R_w^* = Wall thermal resistance at extrapolation conditions(hr-°F-ft^2/ BTU)
A_o = Outside heat transfer surface area (ft^2)
A_i = Inside heat transfer surface area (ft^2)

h_i^* = Inside convection film coefficient at extrapolation conditions (BTU/hr-°F-ft^2)

and

6) $q^* = (1/R^*)\ A_o\ LMTD^* = U^* A_o\ LMTD^*$

where:

q^* = Heat transfer rate at extrapolation conditions (BTU/hr)
R^* = Overall thermal resistance at extrapolation conditions (hr-°F-ft^2/ BTU)
U^* = Overall heat coefficient at extrapolation conditions (BTU/hr-°F-ft^2)
Ao = Heat transfer surface area referenced to outside surface (ft^2)
LMTD* = Log Mean Temperature Difference at extrapolation conditions (°F)

Analytical Uncertainty Calculation Methodology

The method for calculating the analytical uncertainty associated with this performance analysis method is illustrated as follows:

Given a function D = f(A,B,C)

The effect on D of slight changes in the independent variables A, B, and C may be calculated by taking the partial derivatives of D with respect to each of the independent variables. Accordingly, the change in the value of D (i.e., ΔD) due to changes in each of the independent variables (ΔA, ΔB, ΔC) may be represented by the following equation:

$$\Delta D = \frac{\partial D}{\partial A}\Delta A + \frac{\partial D}{\partial B}\Delta B + \frac{\partial D}{\partial C}\Delta C$$

If ΔA, ΔB, ΔC are the known (or estimated) errors of the independent variables, then the error, ΔD, associated with the derived value, D, is calculated. The most probable one standard deviation error representative of ΔD would be the statistical root mean squared value derived as follows:

$$\Delta D = \left[\left(\frac{\partial D}{\partial A}\Delta A\right)^2 + \left(\frac{\partial D}{\partial B}\Delta B\right)^2 + \left(\frac{\partial D}{\partial C}\Delta C\right)^2\right]^{1/2} = U_D$$

Expressing the uncertainty in terms of a percentage of the value of D is simply a matter of including division by the value of D as follows:

$$\frac{U_D}{D} = \left[\left(\frac{\partial D}{\partial A}\right)^2\left(\frac{\Delta A}{D}\right)^2 + \left(\frac{\partial D}{\partial B}\right)^2\left(\frac{\Delta B}{D}\right)^2 + \left(\frac{\partial D}{\partial C}\right)^2\left(\frac{\Delta C}{D}\right)^2\right]^{1/2}$$

The next six sections of this document provide a step by step approach to calculating the analytical uncertainty associated with the six thermal performance equations outlined above. The specific terms to be evaluated from these equations are as follows:

1) Heat transfer area, A_0 and area uncertainty, U_{A_0}
2) Test condition heat transfer rate, q and heat transfer uncertainty, U_q
3) Test condition thermal resistance, R and thermal resistance uncertainty, U_R
4) Observed overall fouling resistance, R_f fouling resistance uncertainty, U_{R_f}
5) Extrapolation condition thermal resistance, R* and thermal resistance uncertainty, U_{R^*}
6) Extrapolation condition heat transfer rate, q* and heat transfer rate uncertainty, U_{q^*}

All uncertainty equations used in this calculation are based on the methods of Reference [1]. It is assumed that all independent variables in each equation have no influence on each other. For example, in Equation (6), LMTD* and the overall heat transfer coefficient, U*, are independent of each other. More specific assumptions are stated in each section as applicable.

For the rating analysis case (i.e., fouling factor is specified and not calculated from test data), equations 2, 3 and 4 above are not applicable because the uncertainty in the specified fouling factor is zero. The analytical uncertainty calculation, therefore, is reduced to an accounting of area uncertainty from equation 1 and the uncertainty in extrapolation terms per equations 5 and 6.

1) Uncertainty in Calculation of Heat Transfer Area (A_o)

Governing Equation

$q = U\, A_o\, LMTD$

For Air Coolers with circular fins, the outside tube surface area, the fin surface area and the total outside surface area are given by the following expressions:

$$A_{o_{Tube}} = \pi\, N_T N_L L_C d_o (1 - \lambda t_{FR})$$

$$A_{o_{Fin}} = \pi \lambda N_T N_L L_C \left[H_F t_{FT} + (H_F + d_o)\sqrt{\left(\frac{H_F - d_o}{2}\right)^2 + \left(\frac{t_{FR} - t_{FT}}{2}\right)^2} \right]$$

$$A_{o_{Total}} = \pi N_T N_L L_C \left\{ d_o(1 - \lambda t_{FR}) + \lambda \left[H_F t_{FT} + (H_F + d_o)\sqrt{\left(\frac{H_F - d_o}{2}\right)^2 + \left(\frac{t_{FR} - t_{FT}}{2}\right)^2} \right] \right\}$$

where:

N_T = Number of tubes per row
N_L = Number of active tube rows
L_C = Effective tube (coil) length (in)
d_o = Tube outside diameter (in)
λ = Fin pitch (fins/inch)
H_F = Fin height (in)
t_{FR} = Thickness of fin at root (in)
t_{FT} = Thickness of fin at tip (in)

For the case where $t_{FR} = t_{FT} = t_F$, the total area equation reduces to the following:

$$A_{o_{Total}} = \pi N_T N_L L_C \left\{ d_o(1 - \lambda t_F) + \lambda \left[H_F t_F + (H_F + d_o)\frac{(H_F - d_o)}{2} \right] \right\}$$

$$A_{o_{Total}} = \pi N_T N_L L_C \left\{ d_o - \lambda d_o t_F + \frac{\lambda}{2}\left[2 H_F t_F + H_F^2 - d_o^2\right] \right\}$$

Assumptions

$U_{N_T} = 0$

$U_{N_L} = 0$

$U_\lambda = 0$

Analysis

$$\frac{U_{Ao}}{A_o} = \left\{ \left(\frac{\partial A_o}{\partial d_o}\right)^2 \left(\frac{U_{d_o}}{A_o}\right)^2 + \left(\frac{\partial A_o}{\partial L_c}\right)^2 \left(\frac{U_{L_c}}{A_o}\right)^2 + \left(\frac{\partial A_o}{\partial t_F}\right)^2 \left(\frac{U_{t_F}}{A_o}\right)^2 + \left(\frac{\partial A_o}{\partial H_F}\right)^2 \left(\frac{U_{H_F}}{A_o}\right)^2 \right\}^{1/2}$$

where,

$$\left(\frac{\partial A_o}{\partial d_o}\right) = \pi N_T N_L L_c \{(1 - \lambda t_F) - \lambda d_o\}$$

$$\left(\frac{\partial A_o}{\partial L_c}\right) = \pi N_T N_L \left\{ d_o - \lambda d_o t_F + \frac{\lambda}{2}\left[2H_F t_F + H_F^2 - d_o^2\right]\right\}$$

$$\left(\frac{\partial A_o}{\partial t_F}\right) = \pi N_T N_L L_c \lambda \{H_F - d_o\}$$

$$\left(\frac{\partial A_o}{\partial H_F}\right) = \pi N_T N_L L_c \lambda \{t_F + H_F\}$$

2) Uncertainty in Calculation of Heat Transfer Rate at Test Conditions

Governing Equation

$$q_{Test} = \dot{m} c_p (T_{c_o} - T_{c_i}) = \rho Q c_p \Delta T$$

Assumptions

$$U_{\Delta T} = 0$$

$$U_{Q_{sw}} = 0$$

(i.e., temperature and flow rate in the governing equation are measured values with no analytical uncertainites)

Analysis

$$\frac{U_{q_{test}}}{q_{test}} = \left[\left(\frac{\partial q_{test}}{\partial \rho} \right)^2 \left(\frac{U_\rho}{q_{test}} \right)^2 + \left(\frac{\partial q_{test}}{\partial Q_{SW}} \right)^2 \left(\frac{U_Q}{q_{test}} \right)^2 + \left(\frac{\partial q_{test}}{\partial c_p} \right)^2 \left(\frac{U_{c_p}}{q_{test}} \right)^2 + \left(\frac{\partial q_{test}}{\partial \Delta T} \right)^2 \left(\frac{U_{\Delta T}}{q_{test}} \right)^2 \right]^{1/2}$$

$$\frac{U_{q_{test}}}{q_{test}} = \left[\left(Q_{SW}\, c_p\, \Delta T \right)^2 \left(\frac{U_\rho}{q_{test}} \right)^2 + \left(\rho Q_{SW}\, \Delta T \right)^2 \left(\frac{U_{c_p}}{q_{test}} \right)^2 \right]^{1/2}$$

3) Uncertainty in Calculation of Thermal Resistance at Test Conditions

Governing Equation

$$R = \frac{1}{U} = \frac{A_o \text{ LMTD}_{\text{Test}}}{q_{\text{Test}}}$$

Assumptions

U_{LMTD} is negligible

Analysis

$$\frac{U_R}{R} = \left[\left(\frac{\partial R}{\partial A_o}\right)^2 \left(\frac{U_{A_o}}{R}\right)^2 + \left(\frac{\partial R}{\partial \text{LMTD}}\right)^2 \left(\frac{U_{\text{LMTD}}}{R}\right)^2 + \left(\frac{\partial R}{\partial q_{\text{test}}}\right)^2 \left(\frac{U_{q_{\text{test}}}}{R}\right)^2 \right]^{1/2}$$

$$\frac{U_R}{R} = \left[\left(\frac{\text{LMTD}}{q_{\text{test}}}\right)^2 \left(\frac{U_{A_o}}{R}\right)^2 + \left(\frac{-A_o\text{LMTD}}{q_{\text{test}}^{\;2}}\right)^2 \left(\frac{U_{q_{\text{test}}}}{R}\right)^2 \right]^{1/2}$$

U_{A_o} (Evaluated in Section 1)

$U_{q_{\text{test}}}$ (Evaluated in Section 2)

4) Uncertainty in Calculation of Fouling Factor at Test Conditions

Governing Equation

$$R_f = R - \frac{1}{h_o \eta_s} - R_w - \left(\frac{A_o}{A_i}\right)\frac{1}{h_i} = R - \frac{1}{h_{o,eff}} - R_w - \left(\frac{A_o}{A_i}\right)\frac{1}{h_i}$$

Where,

$h_{o,eff}$ = effective outside film coefficient = $(h_o) \times (\eta_s)$

Assumptions

$$\left(\frac{\partial R_f}{\partial A_o}\right)^2\left(\frac{U_{A_o}}{R_f}\right)^2 \approx 0$$

$$\left(\frac{\partial R_f}{\partial A_i}\right)^2\left(\frac{U_{A_i}}{R_f}\right)^2 \approx 0$$

(i.e., the uncertainty in dimensions is negligible compared to the thermal resistance and convection coefficient uncertainties)

Analysis

$$\frac{U_{R_f}}{R_f} = \left[\left(\frac{\partial R_f}{\partial R}\right)^2\left(\frac{U_R}{R_f}\right)^2 + \left(\frac{\partial R_f}{\partial h_{o,eff}}\right)^2\left(\frac{U_{h_{o,eff}}}{R_f}\right)^2 + \left(\frac{\partial R_f}{\partial R_w}\right)^2\left(\frac{U_{R_w}}{R_f}\right)^2 + \left(\frac{\partial R_f}{\partial h_i}\right)^2\left(\frac{U_{h_i}}{R_f}\right)^2\right]^{1/2}$$

$$\frac{U_{R_f}}{R_f} = \left[\left(\frac{U_R}{R_f}\right)^2 + \left(\frac{1}{h_{o,eff}^2}\right)^2\left(\frac{U_{h_{o,eff}}}{R_f}\right)^2 + \left(\frac{U_{R_w}}{R_f}\right)^2 + \left(\frac{A_o}{A_i}\frac{1}{h_i^2}\right)^2\left(\frac{U_{h_i}}{R_f}\right)^2\right]^{1/2}$$

U_R (Evaluated in Section 3)

5) Uncertainty in Calculation of Heat Transfer Resistance at Extrapolation Conditions

Governing Equation

$$R^* = R_f + \frac{1}{h_{o,eff}{}^*} + R_w + \left(\frac{A_o}{A_i}\right)\frac{1}{h_i{}^*}$$

Assumptions

$$\left(\frac{\partial R^*}{\partial A_o}\right)^2 \left(\frac{U_{A_o}}{R^*}\right)^2 \approx 0$$

$$\left(\frac{\partial R^*}{\partial A_i}\right)^2 \left(\frac{U_{A_i}}{R^*}\right)^2 \approx 0$$

(i.e., the uncertainty in dimensions is negligible compared to the thermal resistance and convection coefficient uncertainties)

Analysis

$$\frac{U_{R^*}}{R^*} = \left[\left(\frac{\partial R^*}{\partial R_f}\right)^2 \left(\frac{U_{R_f}}{R^*}\right)^2 + \left(\frac{\partial R^*}{\partial h_{o,eff}{}^*}\right)^2 \left(\frac{U_{h_{o,eff}^*}}{R^*}\right)^2 + \left(\frac{\partial R^*}{\partial R_w}\right)^2 \left(\frac{U_{R_w}}{R^*}\right)^2 + \left(\frac{\partial R^*}{\partial h_i{}^*}\right)^2 \left(\frac{U_{h_i^*}}{R^*}\right)^2\right]^{1/2}$$

$$\frac{U_{R^*}}{R^*} = \left[\left(\frac{U_{R_f}}{R^*}\right)^2 + \left(-\frac{1}{h_{o,eff}{}^{*2}}\right)^2 \left(\frac{U_{h_{o,eff}^*}}{R^*}\right)^2 + \left(\frac{U_{R_w}}{R^*}\right)^2 + \left(-\frac{A_o}{A_i}\frac{1}{h_i{}^{*2}}\right)^2 \left(\frac{U_{h_i^*}}{R^*}\right)^2\right]^{1/2}$$

U_{R_f} (Evaluated in Section 4)

U_{R_f} = 0 (for extrapolation calculations only, i.e., no fouling calculation)

6) Uncertainty in Calculation of Heat Transfer Rate at Extrapolation Conditions

Governing Equation

$q^* = (1/R^*)\ (A_o)\ (LMTD^*)$

Assumptions

$U_{LMTD} \approx 0.0$

Analysis

$$\frac{U_{q^*}}{q^*} = \left[\left(\frac{\partial q^*}{\partial R^*} \right)^2 \left(\frac{U_{R^*}}{q^*} \right)^2 + \left(\frac{\partial q^*}{\partial A_o} \right)^2 \left(\frac{U_{Q^*}}{q^*} \right)^2 + \left(\frac{\partial q^*}{\partial \left(LMTD^* \right)} \right)^2 \left(\frac{U_{LMTD^*}}{q^*} \right)^2 \right]^{1/2}$$

$$\frac{U_q^*}{q^*} = \left[\left(-R^{*-2} A_o\ LMTD^* \right)^2 \left(\frac{U_{R^*}}{q^*} \right)^2 + \left(\frac{1}{R^*} LMTD^* \right)^2 \left(\frac{U_{A_o}}{q^*} \right)^2 \right]^{1/2}$$

U_R (Evaluated in Section 5)

U_{A_o} (Evaluated in Section 1)

7) Uncertainty in Calculation of Extrapolated Heat Transfer for Entire Unit

The uncertainties in extrapolated heat transfer, computed for each tube row, are combined in the following manner to yield an overall uncertainty value for the entire air cooler.

$q_{tot} = q_1 + q_2 + q_3 \ldots\ldots + q_n$

where, " n " is the number of tube rows in the unit.

$$\frac{Uq_{tot}}{q_{tot}} = \left[\left(\frac{\partial q_{tot}}{\partial q_1}\right)^2 \left(\frac{Uq_1}{q_{tot}}\right)^2 + \left(\frac{\partial q_{tot}}{\partial q_2}\right)^2 \left(\frac{Uq_2}{q_{tot}}\right)^2 + \left(\frac{\partial q_{tot}}{\partial q_2}\right)^2 \left(\frac{Uq_3}{q_{tot}}\right)^2 + \ldots\ldots\ldots\ldots \left(\frac{\partial q_{tot}}{\partial q_n}\right)^2 \left(\frac{Uq_n}{q_{tot}}\right)^2\right]^{1/2}$$

Assuming that the extrapolated heat transfer rates of the various rows do not depend on each other, the above expression becomes:

$$\frac{Uq_{tot}}{q_{tot}} = \left[\left(\frac{Uq_1}{q_{tot}}\right)^2 + \left(\frac{Uq_2}{q_{tot}}\right)^2 + \left(\frac{Uq_3}{q_{tot}}\right)^2 + \ldots\ldots\ldots\ldots \left(\frac{Uq_n}{q_{tot}}\right)^2\right]^{1/2}$$

Definition of Analytical Uncertainty Analysis Terms

Ao/Ai =	Heat transfer area ratio
di (in) =	Tube inside diameter
Ao (ft^2) =	Outside heat transfer area
do (in) =	Tube outside diameter
Udo/do (%) =	Uncertainty in tube outside diameter (as a percentage)
Udo =	Uncertainty in tube outside diameter (absolute)
Nt =	Number of tubes in given row
Nl =	Number of rows in heat exchanger
Lambda (fins/in) =	Fin pitch
L (Ft) =	Tube length
UL/L (%) =	Uncertainty in tube length (as a percentage)
UL(ft) =	Uncertainty in tube length (absolute)
tfin (in) =	Fin thickness
Utfin/tfin (%) =	Uncertainty in fin thickness (as a percentage)
Utfin (in) =	Uncertainty in fin thickness (absolute)
hfin (in) =	Fin height
Uhfin/hfin (%) =	Uncertainty in fin height (as a percentage)
Uhfin (in) =	Uncertainty in fin height (absolute)
Mdotc (lbm/hr) =	Cooling water mass flow rate
Q (Ft^3/hr) =	Cooling water volumetric flow rate
DT (DegF) =	Cooling water temperature difference (inlet to outlet)
rho (lbm/ft^3) =	Cooling water density
Urho/rho (%) =	Uncertainty in cooling water density (as a percentage)
Urho =	Uncertainty in cooling water density (absolute)
Cp (Btu/lbm/DegF) =	Cooling water specific heat
UCp/Cp (%) =	Uncertainty in cooling water specific heat (as a percentage)
UCp =	Uncertainty in cooling water specific heat (absolute)
qtest (Btu/hr) =	Calculated test heat transfer for coil section
LMTD (DegF) =	Calculated log mean temperature difference
Uo =	Heat transfer coefficient
R = (1/Uo) =	Heat transfer resistance
Rf [(hr-DegF-ft^2)/Btu] =	Fouling resistance
Etas =	
ho [Btu/(hr-DegF-ft^2)] =	Outside film coefficient
ho(eff) [Btu/(hr-DegF-ft^2)] =	Effective outside film coefficient
Uho/ho (%) =	Uncertainty in outside film coefficient (as a percentage)
Uho =	Uncertainty in outside film coefficient (absolute)
hi [Btu/(hr-DegF-ft^2)] =	Inside film coefficient
Uhi/hi (%) =	Uncertainty in inside film coefficient (as a percentage)
Uhi =	Uncertainty in inside film coefficient (absolute)
Rw [(hr-DegF-ft^2)/Btu] =	Wall thermal resistance
URw/Rw (%) =	Uncertainty in wall resistance (as a percentage)
URw =	Uncertainty in wall resistance (absolute)

Proto-Power Calc: 97-199
Attachment: J
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Analytical Uncertainty Analysis -- Uncertainty Inputs

Parameter	Definition	Value (%)	
Udo/do	Uncertainty in tube outside diameter	8.00	(1)
ULc/Lc	Uncertainty in coil (tube) length	0.23	(2)
Utfin/tfin	Uncertainty in fin thickness	4.17	(3)
Uhfin/hfin	Uncertainty in circular fin height	1.38	(4)
Urho/rho	Uncertainty in cooling water density	2.00	(5)
UCp/Cp	Uncertainty in cooling water specific heat	2.00	(5)
Uho/ho	Uncertainty in outside film coefficient	15.00	(6)
Uhi/hi	Uncertainty in inside film coefficient	15.00	(7)
URw/Rw	Uncertainty in wall resistance	2.00	(5)

Notes:

(1) Measurement of 5/8" +/- 0.05" yields an uncertainty of 8.0%

(2) Measurement of 108" +/- 0.25" yields an uncertainty of 0.23%

(3) Specified as 0.012" with estimated tolerance of 0.0005" yields an uncertainty of 4.17%

(4) Measurement of 1.452" +/- 0.02" yields an uncertainty of 1.38%

(5) Uncertainty in property values is estimated as 2%

(6) Uncertainty in outside film coefficient is estimated as 15%

(7) Uncertainty in inside film coefficient is estimated as 15%

15:30:35

PROTO-HX 3.01 by Proto-Power Corporation (SN#PHX-0000) 07/06/98
ComEd -- LaSalle
Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
Limiting Flow Analysis -- 72.5 gpm Case

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31066 acfm	180 gpm
Inlet Dry Bulb Temp	150 °F	105 °F
Inlet Wet Bulb Temp	92 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.8 °F	117.7 °F
Outlet Wet Bulb Temp	84 °F	
Outlet Relative Humidity	%	
Tube Fluid Name		Fresh Water
Tube Fouling Factor		0.002
Air-Side Fouling		0.002
Design Heat Transfer (BTU/hr)		1108000
Atmospheric Pressure		14.315
Sensible Heat Ratio		1
Performance Factor (% Reduction)		0
Heat Exchanger Type		Counter Flow
Fin Type		Circular Fins
Fin Configuration		LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)		108
Fin Pitch (Fins/Inch)		10
Fin Conductivity (BTU/hr·ft·°F)		128
Fin Tip Thickness (inches)		0.012
Fin Root Thickness (inches)		0.012
Circular Fin Height (inches)		1.452
Number of Coils Per Unit		2
Number of Tube Rows		10
Number of Tubes Per Row		24
Active Tubes Per Row		24
Tube Inside Diameter (in)		0.527
Tube Outside Diameter (in)		0.625
Longitudinal Tube Pitch (in)		1.4
Transverse Tube Pitch (in)		1.41
Number of Serpentines		1
Tube Wall Conductivity (BTU/hr·ft·°F)		225

PROTO-HX Report -- Fouling Calculation Output

Fouling Calculation Summary

There is no fouling calculation for the rating analysis case.

Uncertainty in use of design fouling in rating analysis is zero.

Blacked-out areas in the sheets that follow are related to the fouling factor calculation and are not applicable

PROTO-HX Report -- Extrapolation Calculation Output for Limiting Flow Case

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104644.6	89504.32	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	148	100	j Factor	
Outlet Temperature (°F)	106.8483	112	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU)	0.000294
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.037342
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	10532.34
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	1077246
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	1077246
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104644.6	89504.32	Tube-Side hi (BTU/hr·ft²·°F)	1612.69
Inlet Temperature (°F)	148	109.709	j Factor	0.007083
Outlet Temperature (°F)	140.1758	112	Air-Side ho (BTU/hr·ft²·°F)	8.933621
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000294
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft²·°F/BTU)	0.037342
Average Temp (°F)	144.0878	110.8551		
Skin Temperature (°F)	120.3509	112.9962	U Overall (BTU/hr·ft²·°F)	5.880206
Velocity ***	4238.791	5.52875	Effective Area (ft²)	1053.234
Reynold's Number	946.3845 **	36742.29	LMTD	33.07128
Prandtl Number	0.725478	4.006047	Total Heat Transferred (BTU/hr)	204818.2
Bulk Visc (lbm/ft·hr)	0.048993	1.471354		
Skin Visc (lbm/ft·hr)		1.440431	Surface Effectiveness (Eta)	0.921529
Density (lbm/ft³)	0.062393	61.84786	Sensible Heat Transferred (BTU/hr)	204818.2
Cp (BTU/lbm·°F)	0.240245	0.998826	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.016224	0.366848	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104644.6	89504.32	Tube-Side hi (BTU/hr·ft²·°F)	1593.929
Inlet Temperature (°F)	140.1758	107.7758	j Factor	0.007061
Outlet Temperature (°F)	133.5736	109.709	Air-Side ho (BTU/hr·ft²·°F)	8.900292
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000294
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft²·°F/BTU)	0.037342
Average Temp (°F)	136.8747	108.7425		
Skin Temperature (°F)	116.7764	110.5706	U Overall (BTU/hr·ft²·°F)	5.861286
Velocity ***	4238.791	5.526084	Effective Area (ft²)	1053.234
Reynold's Number	955.0962 **	35969.7	LMTD	27.99597
Prandtl Number	0.726116	4.100739	Total Heat Transferred (BTU/hr)	172827.7
Bulk Visc (lbm/ft·hr)	0.048546	1.502958		
Skin Visc (lbm/ft·hr)		1.475547	Surface Effectiveness (Eta)	0.921793
Density (lbm/ft³)	0.063087	61.8777	Sensible Heat Transferred (BTU/hr)	172827.7
Cp (BTU/lbm·°F)	0.240245	0.998847	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.016062	0.366082	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

PROTO-HX Report -- Extrapolation Calculation Output for Limiting Flow Case

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104644.6	89504.32	Tube-Side hi (BTU/hr·ft²·°F)	1578.041
Inlet Temperature (°F)	133.5736	106.143	j Factor	0.007042
Outlet Temperature (°F)	127.9973	107.7758	Air-Side ho (BTU/hr·ft²·°F)	8.872166
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000294
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft²·°F/BTU)	0.037342
Average Temp (°F)	130.7854	106.9595		
Skin Temperature (°F)	113.7605	108.519	U Overall (BTU/hr·ft²·°F)	5.845234
Velocity ***	4238.791	5.52388	Effective Area (ft²)	1053.234
Reynold's Number	962.6409 **	35322.05	LMTD	23.71117
Prandtl Number	0.726616	4.183518	Total Heat Transferred (BTU/hr)	145975.4
Bulk Visc (lbm/ft·hr)	0.048165	1.530515		
Skin Visc (lbm/ft·hr)		1.506367	Surface Effectiveness (Eta)	0.922016
Density (lbm/ft³)	0.063686	61.90239	Sensible Heat Transferred (BTU/hr)	145975.4
Cp (BTU/lbm·°F)	0.240245	0.99887	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015925	0.365426	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104644.6	89504.32	Tube-Side hi (BTU/hr·ft²·°F)	1564.579
Inlet Temperature (°F)	127.9973	104.7628	j Factor	0.007025
Outlet Temperature (°F)	123.2834	106.143	Air-Side ho (BTU/hr·ft²·°F)	8.84841
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000294
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft²·°F/BTU)	0.037342
Average Temp (°F)	125.6403	105.453		
Skin Temperature (°F)	111.2133	106.7826	U Overall (BTU/hr·ft²·°F)	5.831615
Velocity ***	4238.791	5.522051	Effective Area (ft²)	1053.234
Reynold's Number	969.1571 **	34778.02	LMTD	20.0905
Prandtl Number	0.72701	4.255589	Total Heat Transferred (BTU/hr)	123397
Bulk Visc (lbm/ft·hr)	0.047841	1.554457		
Skin Visc (lbm/ft·hr)		1.533295	Surface Effectiveness (Eta)	0.922204
Density (lbm/ft³)	0.064201	61.9229	Sensible Heat Transferred (BTU/hr)	123397
Cp (BTU/lbm·°F)	0.240245	0.998893	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015809	0.364865	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104644.6	89504.32	Tube-Side hi (BTU/hr·ft²·°F)	1553.173
Inlet Temperature (°F)	123.2834	103.5953	j Factor	0.007011
Outlet Temperature (°F)	119.2958	104.7628	Air-Side ho (BTU/hr·ft²·°F)	8.828331
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000294
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft²·°F/BTU)	0.037342
Average Temp (°F)	121.2894	104.1795		
Skin Temperature (°F)	109.0602	105.3123	U Overall (BTU/hr·ft²·°F)	5.820059
Velocity ***	4238.791	5.520528	Effective Area (ft²)	1053.234
Reynold's Number	974.7719 **	34320.49	LMTD	17.02872
Prandtl Number	0.727321	4.318086	Total Heat Transferred (BTU/hr)	104384.1
Bulk Visc (lbm/ft·hr)	0.047566	1.57518		
Skin Visc (lbm/ft·hr)		1.556723	Surface Effectiveness (Eta)	0.922363
Density (lbm/ft³)	0.064643	61.93997	Sensible Heat Transferred (BTU/hr)	104384.1
Cp (BTU/lbm·°F)	0.240245	0.998915	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015712	0.364387	Heat to Condensate (BTU/hr)	

PROTO-HX Report -- Extrapolation Calculation Output for Limiting Flow Case

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104644.6	89504.32	Tube-Side hi (BTU/hr·ft²·°F)	1543.495
Inlet Temperature (°F)	119.2958	102.6071	j Factor	0.006999
Outlet Temperature (°F)	115.9206	103.5953	Air-Side ho (BTU/hr·ft²·°F)	8.811349
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000294
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft²·°F/BTU)	0.037342
Average Temp (°F)	117.6082	103.101		
Skin Temperature (°F)	107.2384	104.066	U Overall (BTU/hr·ft²·°F)	5.81025
Velocity ***	4238.791	5.519256	Effective Area (ft²)	1053.234
Reynold's Number	979.5995 **	33934.63	LMTD	14.4379
Prandtl Number	0.727568	4.372184	Total Heat Transferred (BTU/hr)	88353.51
Bulk Visc (lbm/ft·hr)	0.047331	1.59309		
Skin Visc (lbm/ft·hr)		1.577049	Surface Effectiveness (Eta)	0.922498
Density (lbm/ft³)	0.065022	61.95425	Sensible Heat Transferred (BTU/hr)	88353.51
Cp (BTU/lbm·°F)	0.240245	0.998935	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015629	0.363978	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104644.6	89504.32	Tube-Side hi (BTU/hr·ft²·°F)	1535.286
Inlet Temperature (°F)	115.9206	101.7702	j Factor	0.006989
Outlet Temperature (°F)	113.0624	102.6071	Air-Side ho (BTU/hr·ft²·°F)	8.796979
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000294
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft²·°F/BTU)	0.037342
Average Temp (°F)	114.4917	102.1879		
Skin Temperature (°F)	105.6963	103.0096	U Overall (BTU/hr·ft²·°F)	5.801925
Velocity ***	4238.791	5.518191	Effective Area (ft²)	1053.234
Reynold's Number	983.7432 **	33609.16	LMTD	12.24441
Prandtl Number	0.727765	4.418844	Total Heat Transferred (BTU/hr)	74822.97
Bulk Visc (lbm/ft·hr)	0.047132	1.608518		
Skin Visc (lbm/ft·hr)		1.594624	Surface Effectiveness (Eta)	0.922612
Density (lbm/ft³)	0.065347	61.96621	Sensible Heat Transferred (BTU/hr)	74822.97
Cp (BTU/lbm·°F)	0.240244	0.998954	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015559	0.363629	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104644.6	89504.32	Tube-Side hi (BTU/hr·ft²·°F)	1528.334
Inlet Temperature (°F)	113.0624	101.0612	j Factor	0.006981
Outlet Temperature (°F)	110.6407	101.7702	Air-Side ho (BTU/hr·ft²·°F)	8.784811
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000294
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft²·°F/BTU)	0.037342
Average Temp (°F)	111.8516	101.4156		
Skin Temperature (°F)	104.3909	102.1149	U Overall (BTU/hr·ft²·°F)	5.794861
Velocity ***	4238.791	5.5173	Effective Area (ft²)	1053.234
Reynold's Number	987.2948 **	33334.75	LMTD	10.38637
Prandtl Number	0.727923	4.458934	Total Heat Transferred (BTU/hr)	63391.63
Bulk Visc (lbm/ft·hr)	0.046963	1.621759		
Skin Visc (lbm/ft·hr)		1.609762	Surface Effectiveness (Eta)	0.922708
Density (lbm/ft³)	0.065624	61.97622	Sensible Heat Transferred (BTU/hr)	63391.63

PROTO-HX Report -- Extrapolation Calculation Output for Limiting Flow Case

Cp (BTU/lbm·°F)	0.240244	0.99897	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0155	0.363332	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104644.6	89504.32	Tube-Side hi (BTU/hr·ft^2·°F)	1522.43
Inlet Temperature (°F)	110.6407	100.4603	j Factor	0.006973
Outlet Temperature (°F)	108.5883	101.0612	Air-Side ho (BTU/hr·ft^2·°F)	8.774505
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft^2·°F/BTU)	0.000294
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft^2·°F/BTU)	0.037342
Average Temp (°F)	109.6146	100.7607		
Skin Temperature (°F)	103.2846	101.3556	U Overall (BTU/hr·ft^2·°F)	5.788863
Velocity ***	4238.791	5.51655	Effective Area (ft^2)	1053.234
Reynold's Number	990.3344 **	33102.65	LMTD	8.81192
Prandtl Number	0.72805	4.493396	Total Heat Transferred (BTU/hr)	53726.53
Bulk Visc (lbm/ft·hr)	0.046818	1.63313		
Skin Visc (lbm/ft·hr)		1.622796	Surface Effectiveness (Eta)	0.92279
Density (lbm/ft^3)	0.065861	61.98464	Sensible Heat Transferred (BTU/hr)	53726.53
Cp (BTU/lbm·°F)	0.240244	0.998985	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015449	0.36308	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	104644.6	89504.32	Tube-Side hi (BTU/hr·ft^2·°F)	1517.421
Inlet Temperature (°F)	108.5883	99.95088	j Factor	0.006967
Outlet Temperature (°F)	106.8483	100.4603	Air-Side ho (BTU/hr·ft^2·°F)	8.765772
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft^2·°F/BTU)	0.000294
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft^2·°F/BTU)	0.037342
Average Temp (°F)	107.7184	100.2055		
Skin Temperature (°F)	102.3469	100.7115	U Overall (BTU/hr·ft^2·°F)	5.783772
Velocity ***	4238.791	5.515919	Effective Area (ft^2)	1053.234
Reynold's Number	992.9331 **	32906.36	LMTD	7.477258
Prandtl Number	0.728154	4.522943	Total Heat Transferred (BTU/hr)	45548.96
Bulk Visc (lbm/ft·hr)	0.046696	1.642872		
Skin Visc (lbm/ft·hr)		1.633988	Surface Effectiveness (Eta)	0.922859
Density (lbm/ft^3)	0.066063	61.99173	Sensible Heat Transferred (BTU/hr)	45548.96
Cp (BTU/lbm·°F)	0.240244	0.998992	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015407	0.362865	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 1)

I. PROTO-HX Output -- Fouling Calculation

[redacted]

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 29.80114791
Ao (ft^2) = 1053.234205
Ao/Ai = 35 34206831
do (ft) = 0 052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 24
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 9
UL/L (%) = 0.23
UL(ft) = 0.0207

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.121
Uhfin/hfin (%) = 1.38
Uhfin (ft) = 0.0016698

Mdotc* (lbm/hr) = 89504.32386
Q* (Ft^3/hr) = 1447.169301
DT* (DegF) = 2.291020744
rho* (lbm/ft^3) = 61.84785966
Urho*/rho* (%) = 2
Urho* = 1.236957193

Cp* (Btu/lbm/DegF) = 0.998825556
UCp*/Cp* (%) = 2
UCp* = 0.019976511

q* (Btu/hr) = 204818.174
LMTD* (DegF) = 33.07128037
Uo* = 5.880205797
R* = (1/Uo*) = 0.170062075
Rf [(hr-DegF-ft^2)/Btu] = 0.037342068
Etas = 0.921529454
ho* [Btu/(hr-DegF-ft^2)] = 8.933620538
ho*(eff) [Btu/(hr-DegF-ft^2)] = 8.232594451
Uho*/ho* (%) = 15
Uho* = 1.234889168

hi* [Btu/(hr-DegF-ft^2)] = 1612 689954
Uhi*/hi* (%) = 15
Uhi* = 241.903493

Rw* [(hr-DegF-ft^2)/Btu] = 0.000294126
URw*/Rw* (%) = 2
URw* = 5.88252E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 1)

1 **Analytical Uncertainty in Heat Transfer Surface Area**

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
1053.23421	0.05208	0.00417	9.00000	0.02070	0.00100	0.00004	0.12100	0.00167	0.04277	45.04379
Derivatives:	-7287.99		117.03		11223.78		19868.94			

2 **Analytical Uncertainty in Test Heat Transfer Rate**

[redacted]

3 **Analytical Uncertainty in Observed Heat Transfer Resistance (R):**

[redacted]

4 **Analytical Uncertainty in Observed Rf**

[redacted]

5 **Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:**

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.17006	8.23259	1.23489	1612.68995	241.90349	0.00029	0.00001	0.03734	0.00000	0.10887	0.01851

6 **Analytical Uncertainty in Extrapolated Heat Transfer**

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
204818.1740	0.17006	0.01851	1053.23421	45.04379	33.07128	0.11697	23957.07518

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Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 2)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 29.80114791
Ao (ft^2) = 1053.234205
Ao/Ai = 35.34206831
do (ft) = 0 052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 24
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 9
UL/L (%) = 0.23
UL(ft) = 0.0207

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.121
Uhfin/hfin (%) = 1.38
Uhfin (ft) = 0.0016698

Mdotc* (lbm/hr) = 89504.32386
Q* (Ft^3/hr) = 1446.47149
DT* (DegF) = 1.933182933
rho* (lbm/ft^3) = 61.87769648
Urho*/rho* (%) = 2
Urho* = 1.23755393

Cp* (Btu/lbm/DegF) = 0.998846891
UCp*/Cp* (%) = 2
UCp* = 0.019976938

q* (Btu/hr) = 172827.7249
LMTD* (DegF) = 27.99597397
Uo* = 5.861285511
R* = (1/Uo*) = 0.170611037
Rf [(hr-DegF-ft^2)/Btu] = 0.037342068
Etas = 0 92179308
ho* [Btu/(hr-DegF-ft^2)] = 8.900292032
ho*(eff) [Btu/(hr-DegF-ft^2)] = 8 204227601
Uho*/ho* (%) = 15
Uho* = 1.23063414

hi* [Btu/(hr-DegF-ft^2)] = 1593.928753
Uhi*/hi* (%) = 15
Uhi* = 239.0893129

Rw* [(hr-DegF-ft^2)/Btu] = 0.000294126
URw*/Rw* (%) = 2
URw* = 5.88252E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 2)

1 **Analytical Uncertainty in Heat Transfer Surface Area**

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
1053.23421	0.05208	0.00417	9.00000	0.02070	0.00100	0.00004	0.12100	0.00167	0.04277	45.04379
Derivatives:	-7287.99		117.03		11223.78		19868.94			

2 **Analytical Uncertainty in Test Heat Transfer Rate**

[redacted]

3 **Analytical Uncertainty in Observed Heat Transfer Resistance (R):**

[redacted]

4 **Analytical Uncertainty in Observed Rf**

[redacted]

5 **Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:**

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.17061	8.20423	1.23063	1593.92875	239.08931	0.00029	0.00001	0.03734	0.00000	0.10892	0.01858

6 **Analytical Uncertainty in Extrapolated Heat Transfer**

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
172827.7249	0.17061	0.01858	1053.23421	45.04379	27.99597	0.11702	20223.83227

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 3)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 29 80114791
Ao (ft^2) = 1053.234205
Ao/Ai = 35.34206831
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 24
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 9
UL/L (%) = 0 23
UL(ft) = 0 0207

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.121
Uhfin/hfin (%) = 1.38
Uhfin (ft) = 0.0016698

Mdotc* (lbm/hr) = 89504.32386
Q* (Ft^3/hr) = 1445.894511
DT* (DegF) = 1.632788002
rho* (lbm/ft^3) = 61.90238859
Urho*/rho* (%) = 2
Urho* = 1.238047772

Cp* (Btu/lbm/DegF) = 0.998869857
UCp*/Cp* (%) = 2
UCp* = 0.019977397

q* (Btu/hr) = 145975.4497
LMTD* (DegF) = 23.71116759
Uo* = 5.845234335
R* = (1/Uo*) = 0.17107954
Rf [(hr-DegF-ft^2)/Btu] = 0.037342068
Etas = 0.92201571
ho* [Btu/(hr-DegF-ft^2)] = 8.872165657
ho*(eff) [Btu/(hr-DegF-ft^2)] = 8.180276116
Uho*/ho* (%) = 15
Uho* = 1 227041417

hi* [Btu/(hr-DegF-ft^2)] = 1578.040982
Uhi*/hi* (%) = 15
Uhi* = 236.7061473

Rw* [(hr-DegF-ft^2)/Btu] = 0.000294126
URw*/Rw* (%) = 2
URw* = 5.88252E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 3)

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
1053.23421	0.05208	0.00417	9.00000	0.02070	0.00100	0.00004	0.12100	0.00167	0.04277	45.04379
Derivatives:	-7287.99		117.03		11223.78		19868.94			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.17108	8.18028	1.22704	1578.04098	236.70615	0.00029	0.00001	0.03734	0.00000	0.10897	0.01864

6 Analytical Uncertainty in Extrapolated Heat Transfer

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
145975.4497	0.17108	0.01864	1053.23421	45.04379	23.71117	0.11706	17087.72434

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 4)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 29.80114791
Ao (ft^2) = 1053.234205
Ao/Ai = 35.34206831
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 24
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 9
UL/L (%) = 0.23
UL(ft) = 0.0207

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.121
Uhfin/hfin (%) = 1.38
Uhfin (ft) = 0.0016698

Mdotc* (lbm/hr) = 89504.32386
Q* (Ft^3/hr) = 1445.415652
DT* (DegF) = 1.380210229
rho* (lbm/ft^3) = 61.92289654
Urho*/rho* (%) = 2
Urho* = 1.238457931

Cp* (Btu/lbm/DegF) = 0.998892815
UCp*/Cp* (%) = 2
UCp* = 0.019977856

q* (Btu/hr) = 123396.9987
LMTD* (DegF) = 20.09050152
Uo* = 5.831615259
R* = (1/Uo*) = 0.171479077
Rf [(hr-DegF-ft^2)/Btu] = 0.037342066
Etas = 0.922203852
ho* [Btu/(hr-DegF-ft^2)] = 8.848410099
ho*(eff) [Btu/(hr-DegF-ft^2)] = 8.160037881
Uho*/ho* (%) = 15
Uho* = 1.224005682

hi* [Btu/(hr-DegF-ft^2)] = 1564.579311
Uhi*/hi* (%) = 15
Uhi* = 234.6868967

Rw* [(hr-DegF-ft^2)/Btu] = 0.000294126
URw*/Rw* (%) = 2
URw* = 5.88252E-06

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Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 4)

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
1053.23421	0.05208	0.00417	9.00000	0.02070	0.00100	0.00004	0.12100	0.00167	0.04277	45.04379
Derivatives:	-7287.99		117.03		11223.78		19868.94			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.17148	8.16004	1.22401	1564.57931	234.68690	0.00029	0.00001	0.03734	**0.00000**	0.10900	0.01869

6 Analytical Uncertainty in Extrapolated Heat Transfer

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
123396.9987	0.17148	0.01869	1053.23421	45.04379	20.09050	0.11709	14449.01463

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 5)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 29.80114791
Ao (ft^2) = 1053.234205
Ao/Ai = 35.34206831
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 24
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 9
UL/L (%) = 0.23
UL(ft) = 0.0207

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.121
Uhfin/hfin (%) = 1.38
Uhfin (ft) = 0.0016698

Mdotc* (lbm/hr) = 89504.32386
Q* (Ft^3/hr) = 1445.017129
DT* (DegF) = 1.167483495
rho* (lbm/ft^3) = 61.9399743
Urho*/rho* (%) = 2
Urho* = 1.238799486

Cp* (Btu/lbm/DegF) = 0.998914777
UCp*/Cp* (%) = 2
UCp* = 0.019978296

q* (Btu/hr) = 104384.088
LMTD* (DegF) = 17.02871803
Uo* = 5.820059059
R* = (1/Uo*) = 0.171819562
Rf [(hr-DegF-ft^2)/Btu] = 0.037342068
Etas = 0.922362959
ho* [Btu/(hr-DegF-ft^2)] = 8.82833058
ho*(eff) [Btu/(hr-DegF-ft^2)] = 8.142925116
Uho*/ho* (%) = 15
Uho* = 1.221438767

hi* [Btu/(hr-DegF-ft^2)] = 1553.173136
Uhi*/hi* (%) = 15
Uhi* = 232.9759705

Rw* [(hr-DegF-ft^2)/Btu] = 0.000294126
URw*/Rw* (%) = 2
URw* = 5.88252E-06

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Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 5)

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
1053.23421	0.05208	0.00417	9.00000	0.02070	0.00100	0.00004	0.12100	0.00167	0.04277	45.04379
Derivatives:	-7287.99		117.03		11223.78		19868.94			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.17182	8.14293	1.22144	1553.17314	232.97597	0.00029	0.00001	0.03734	**0.00000**	0.10904	0.01873

6 Analytical Uncertainty in Extrapolated Heat Transfer

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
104384.0880	0.17182	0.01873	1053.23421	45.04379	17.02872	0.11712	12225.77360

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 6)

I. PROTO-HX Output -- Fouling Calculation

[redacted]

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 29.80114791
Ao (ft^2) = 1053.234205
Ao/Ai = 35.34206831
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 24
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 9
UL/L (%) = 0.23
UL(ft) = 0.0207

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.121
Uhfin/hfin (%) = 1.38
Uhfin (ft) = 0.0016698

Mdotc* (lbm/hr) = 89504.32386
Q* (Ft^3/hr) = 1444.684108
DT* (DegF) = 0.988218343
rho* (lbm/ft^3) = 61.95425241
Urho*/rho* (%) = 2
Urho* = 1.239085048

Cp* (Btu/lbm/DegF) = 0.998935192
UCp*/Cp* (%) = 2
UCp* = 0.019978704

q* (Btu/hr) = 88353.50562
LMTD* (DegF) = 14.43789828
Uo* = 5.810250449
R* = (1/Uo*) = 0.172109621
Rf [(hr-DegF-ft^2)/Btu] = 0.037342068
Etas = 0.92249757
ho* [Btu/(hr-DegF-ft^2)] = 8.811349455
ho*(eff) [Btu/(hr-DegF-ft^2)] = 8.12844846
Uho*/ho* (%) = 15
Uho* = 1.219267269

hi* [Btu/(hr-DegF-ft^2)] = 1543.494571
Uhi*/hi* (%) = 15
Uhi* = 231.5241857

Rw* [(hr-DegF-ft^2)/Btu] = 0.000294126
URw*/Rw* (%) = 2
URw* = 5.88252E-06

Proto-Power Calc: 97-199
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Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 6)

1 **Analytical Uncertainty in Heat Transfer Surface Area**

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
1053.23421	0.05208	0.00417	9.00000	0.02070	0.00100	0.00004	0.12100	0.00167	0.04277	45.04379
Derivatives:	-7287.99		117.03		11223.78		19868.94			

2 **Analytical Uncertainty in Test Heat Transfer Rate**

[redacted]

3 **Analytical Uncertainty in Observed Heat Transfer Resistance (R):**

[redacted]

4 **Analytical Uncertainty in Observed Rf**

[redacted]

5 **Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:**

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.17211	8.12845	1.21927	1543.49457	231.52419	0.00029	0.00001	0.03734	**0.00000**	0.10906	0.01877

6 **Analytical Uncertainty in Extrapolated Heat Transfer**

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
88353.5056	0.17211	0.01877	1053.23421	45.04379	14.43790	0.11715	10350.39262

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 7)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) =	0.043916667
Ai (ft^2) =	29.80114791
Ao (ft^2) =	1053.234205
Ao/Ai =	35.34206831
do (ft) =	0.052083333
Udo/do (%) =	8
Udo (ft) =	0.004166667
Nt =	24
Nl =	2
Lambda (fins/ft) =	120
L (ft) =	9
UL/L (%) =	0.23
UL(ft) =	0.0207
tfin (ft) =	0.001
Utfin/tfin (%) =	4.17
Utfin (ft) =	0.0000417
hfin (ft) =	0.121
Uhfin/hfin (%) =	1.38
Uhfin (ft) =	0.0016698
Mdotc* (lbm/hr) =	89504.32386
Q* (Ft^3/hr) =	1444.405412
DT* (DegF) =	0.836912872
rho* (lbm/ft^3) =	61.96620637
Urho*/rho* (%) =	2
Urho* =	1.239324127
Cp* (Btu/lbm/DegF) =	0.998953792
UCp*/Cp* (%) =	2
UCp* =	0.019979076
q* (Btu/hr) =	74822.96581
LMTD* (DegF) =	12.24440881
Uo* =	5.801925428
R* = (1/Uo*) =	0.172356576
Rf [(hr-DegF-ft^2)/Btu] =	0.037342068
Etas =	0.922611524
ho* [Btu/(hr-DegF-ft^2)] =	8.796979195
ho*(eff) [Btu/(hr-DegF-ft^2)] =	8.116194385
Uho*/ho* (%) =	15
Uho* =	1.217429158
hi* [Btu/(hr-DegF-ft^2)] =	1535.286389
Uhi*/hi* (%) =	15
Uhi* =	230.2929584
Rw* [(hr-DegF-ft^2)/Btu] =	0.000294126
URw*/Rw* (%) =	2
URw* =	5.88252E-06

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Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 7)

1 **Analytical Uncertainty in Heat Transfer Surface Area**

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
1053.23421	0.05208	0.00417	9.00000	0.02070	0.00100	0.00004	0.12100	0.00167	0.04277	45.04379
Derivatives:	-7287.99		117.03		11223.78		19868.94			

2 **Analytical Uncertainty in Test Heat Transfer Rate**

[redacted]

3 **Analytical Uncertainty in Observed Heat Transfer Resistance (R):**

[redacted]

4 **Analytical Uncertainty in Observed Rf**

[redacted]

5 **Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:**

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.17236	8.11619	1.21743	1535.28639	230.29296	0.00029	0.00001	0.03734	**0.00000**	0.10908	0.01880

6 **Analytical Uncertainty in Extrapolated Heat Transfer**

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
74822.9658	0.17236	0.01880	1053.23421	45.04379	12.24441	0.11717	8766.86859

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 8)

I. PROTO-HX Output -- Fouling Calculation

[redacted]

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0 043916667
Ai (ft^2) = 29.80114791
Ao (ft^2) = 1053.234205
Ao/Ai = 35.34206831
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0 004166667

Nt = 24
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 9
UL/L (%) = 0.23
UL(ft) = 0.0207

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.121
Uhfin/hfin (%) = 1.38
Uhfin (ft) = 0.0016698

Mdotc* (lbm/hr) = 89504.32386
Q* (Ft^3/hr) = 1444.172055
DT* (DegF) = 0.708992087
rho* (lbm/ft^3) = 61.9762192
Urho*/rho* (%) = 2
Urho* = 1.239524384

Cp* (Btu/lbm/DegF) = 0.998970492
UCp*/Cp* (%) = 2
UCp* = 0.01997941

q* (Btu/hr) = 63391.62803
LMTD* (DegF) = 10.38637332
Uo* = 5.794860986
R* = (1/Uo*) = 0.172566694
Rf [(hr-DegF-ft^2)/Btu] = 0 037342068
Etas = 0.922708045
ho* [Btu/(hr-DegF-ft^2)] = 8.784811073
ho*(eff) [Btu/(hr-DegF-ft^2)] = 8.105815848
Uho*/ho* (%) = 15
Uho* = 1.215872377

hi* [Btu/(hr-DegF-ft^2)] = 1528.333644
Uhi*/hi* (%) = 15
Uhi* = 229.2500465

Rw* [(hr-DegF-ft^2)/Btu] = 0.000294126
URw*/Rw* (%) = 2
URw* = 5 88252E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 8)

1 **Analytical Uncertainty in Heat Transfer Surface Area**

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
1053.23421	0.05208	0.00417	9.00000	0.02070	0.00100	0.00004	0.12100	0 00167	0.04277	45.04379
Derivatives:	-7287.99		117.03		11223.78		19868.94			

2 **Analytical Uncertainty in Test Heat Transfer Rate**

[redacted]

3 **Analytical Uncertainty in Observed Heat Transfer Resistance (R):**

[redacted]

4 **Analytical Uncertainty in Observed Rf**

[redacted]

5 **Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:**

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.17257	8.10582	1.21587	1528.33364	229.25005	0.00029	0.00001	0.03734	**0.00000**	0.10910	0.01883

6 **Analytical Uncertainty in Extrapolated Heat Transfer**

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
63391.6280	0.17257	0.01883	1053.23421	45.04379	10.38637	0.11719	7428.58409

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Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 9)

I. PROTO-HX Output -- Fouling Calculation

[redacted]

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 29.80114791
Ao (ft^2) = 1053.234205
Ao/Ai = 35.34206831
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 24
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 9
UL/L (%) = 0.23
UL(ft) = 0.0207

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.121
Uhfin/hfin (%) = 1.38
Uhfin (ft) = 0.0016698

Mdotc* (lbm/hr) = 89504.32386
Q* (Ft^3/hr) = 1443.975836
DT* (DegF) = 0.600887156
rho* (lbm/ft^3) = 61.98464105
Urho*/rho* (%) = 2
Urho* = 1.239692821

Cp* (Btu/lbm/DegF) = 0.998985324
UCp*/Cp* (%) = 2
UCp* = 0.019979706

q* (Btu/hr) = 53726.53071
LMTD* (DegF) = 8.811920175
Uo* = 5.788863224
R* = (1/Uo*) = 0.172745488
Rf [(hr-DegF-ft^2)/Btu] = 0.037342068
Etas = 0.922789817
ho* [Btu/(hr-DegF-ft^2)] = 8.774504759
ho*(eff) [Btu/(hr-DegF-ft^2)] = 8.097023643
Uho*/ho* (%) = 15
Uho* = 1.214553546

hi* [Btu/(hr-DegF-ft^2)] = 1522.430278
Uhi*/hi* (%) = 15
Uhi* = 228.3645418

Rw* [(hr-DegF-ft^2)/Btu] = 0.000294126
URw*/Rw* (%) = 2
URw* = 5.88252E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 9)

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
1053.23421	0.05208	0.00417	9.00000	0.02070	0.00100	0.00004	0.12100	0.00167	0.04277	45.04379
Derivatives:	-7287.99		117.03		11223.78		19868.94			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.17275	8.09702	1.21455	1522.43028	228.36454	0.00029	0.00001	0.03734	0.00000	0.10912	0.01885

6 Analytical Uncertainty in Extrapolated Heat Transfer

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
53726.5307	0.17275	0.01885	1053.23421	45.04379	8.81192	0.11720	6296.76278

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 10)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 29.80114791
Ao (ft^2) = 1053.234205
Ao/Ai = 35 34206831
do (ft) = 0 052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 24
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 9
UL/L (%) = 0.23
UL(ft) = 0.0207

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.121
Uhfin/hfin (%) = 1.38
Uhfin (ft) = 0.0016698

Mdotc* (lbm/hr) = 89504.32386
Q* (Ft^3/hr) = 1443.810733
DT* (DegF) = 0.509422401
rho* (lbm/ft^3) = 61.99172812
Urho*/rho* (%) = 2
Urho* = 1.239834582

Cp* (Btu/lbm/DegF) = 0.998991801
UCp*/Cp* (%) = 2
UCp* = 0.019979836

q* (Btu/hr) = 45548.95806
LMTD* (DegF) = 7.477257887
Uo* = 5.783771572
R* = (1/Uo*) = 0.172897561
Rf [(hr-DegF-ft^2)/Btu] = 0.037342068
Etas = 0.922859123
ho* [Btu/(hr-DegF-ft^2)] = 8 765771633
ho*(eff) [Btu/(hr-DegF-ft^2)] = 8.089572318
Uho*/ho* (%) = 15
Uho* = 1.213435848

hi* [Btu/(hr-DegF-ft^2)] = 1517.421208
Uhi*/hi* (%) = 15
Uhi* = 227.6131811

Rw* [(hr-DegF-ft^2)/Btu] = 0.000294126
URw*/Rw* (%) = 2
URw* = 5 88252E-06

Proto-Power Calc: 97-199
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Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 10)

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
1053.23421	0.05208	0.00417	9.00000	0.02070	0.00100	0.00004	0.12100	0.00167	0.04277	45.04379
Derivatives:	-7287.99		117.03		11223.78		19868.94			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.17290	8.08957	1.21344	1517.42121	227.61318	0.00029	0.00001	0.03734	0.00000	0.10913	0.01887

6 Analytical Uncertainty in Extrapolated Heat Transfer

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
45548.9581	0.17290	0.01887	1053.23421	45.04379	7.47726	0.11721	5338.91366

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate

	Extrapolated Heat Transfer (Btu/hr)	Calculated Uncertainty (Btu/hr)	(Uq/q)^2
Row1	204818.1740	23957.0752	0.000495
Row2	172827.7249	20223.8323	0.000352
Row3	145975.4497	17087.7243	0.000252
Row4	123396.9987	14449.0146	0.000180
Row5	104384.0880	12225.7736	0.000129
Row6	88353.5056	10350.3926	0.000092
Row7	74822.9658	8766.8686	0.000066
Row8	63391.6280	7428.5841	0.000048
Row9	53726.5307	6296.7628	0.000034
Row10	45548.9581	5338.9137	0.000025
	1077246.0236	**44051.1569**	**0.040892**
	qtot	**SRSS**	**SRSS**

Uqtot/qtot = **4.09%**

(180 gpm Case)

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate

	Extrapolated Heat Transfer (Btu/hr)	Calculated Uncertainty (Btu/hr)	(Uq/q)^2
Row1	123421.7443	14238.0167	0.000230
Row2	115581.9845	13337.4092	0.000202
Row3	108279.4713	12498.2201	0.000177
Row4	101473.2524	11715.7928	0.000156
Row5	95125.8622	10985.8637	0.000137
Row6	89203.2338	10304.5540	0.000121
Row7	83673.9831	9668.2876	0.000106
Row8	78509.4314	9073.7955	0.000094
Row9	73683.3994	8518.0925	0.000082
Row10	69171.4500	7998.3902	0.000073
	938123.8123	**34832.2787**	**0.037130**
	qtot	**SRSS**	**SRSS**

Uqtot/qtot = **3.71%**

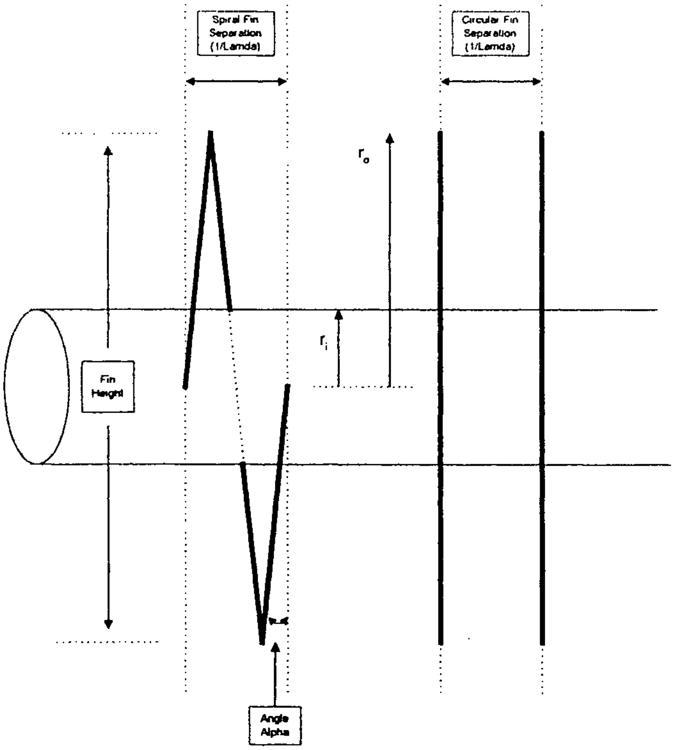
(72.5 gpm Case)

Attachment K to
Proto-Power Calculation
97-199
Revision A

COMPARING SPIRAL AND CIRCULAR FINS

Area Calculation

A view of the spiral fin layout as compared to the circular fin layout is provided below. Let angle α represent the angle between the plane of the circular fin and the plane of the spiral fin.



A differential area in the circular fin is given as:

$$dA = rdrd\theta$$

The expression for circular fin surface area (times 2 for both sides and disregarding the edge area) taken over a complete traverse of the tube is given as:

$$A_{cf} = 2\int_{ri}^{ro}\int_{0}^{2\pi} rdrd\theta = 2\pi(r_o^2 - r_i^2)$$

Where:

r_o = the fin outside radius which is one half the fin height

r_i = the inside fin radius which is the tube outside radius

The spiral fin surface area (times 2 for both sides and disregarding the edge area) can be approximated by the expression:

$$A_{sf} = \left(\frac{1}{\cos\alpha}\right) 2\pi(r_o^2 - r_i^2)$$

The ratio of the two areas becomes:

$$\frac{A_{sf}}{A_{cf}} = \left(\frac{1}{\cos\alpha}\right)$$

Angle α is approximated by the expression:

$$\tan\alpha = \frac{\frac{1}{4}(\text{fin separation})}{r_o} = \frac{1}{4r_o\lambda}$$

$$\alpha = \tan^{-1}\left(\frac{1}{4r_o\lambda}\right)$$

where:
λ = fin pitch

Substituting fin height into the expression yields the following:

$$\alpha = \tan^{-1}\left(\frac{2}{4H_f\lambda}\right) = \tan^{-1}\left(\frac{1}{2H_f\lambda}\right)$$

As the angle α goes to zero, the spiral fin area approaches that of the circular fin. It can be seen that for very small fin separations (i.e., high fin pitch) the smaller the resulting angle α.

For the case of the VY cooler fin geometry:

$$\alpha = \tan^{-1}\left(\frac{1}{2H_f\lambda}\right) = \tan^{-1}\left(\frac{1}{2(1.487)(10)}\right) = \tan^{-1}(0.033625) = 1.93^\circ$$

The resulting area ratio is then:

$$\frac{A_{sf}}{A_{cf}} = \left(\frac{1}{\cos\alpha}\right) = \left(\frac{1}{\cos(1.93^{\circ})}\right) = 1.00057$$

This difference is negligible and is bounded by the uncertainty in the analysis presented in Attachment J.

Heat Transfer Coefficient

The fin geometry affects the calculation of the outside heat transfer film coefficient (h_o) for condensing modes of operation. Vertical (circular) fins provide for better condensation heat transfer since the condensate falls away from the fins at a faster rate than if the fin were inclined (i.e., spiral geometry). As shown in the area discussion above, the angular difference between the circular fin geometry and the spriral fin geometry for the VY coils with a fin pitch of 10 fins per inch is very small (i.e., <2°). The angle of incline, therefore, is deemed to be sufficiently small as to make the difference between circular and spiral fin geometries negligible even for condensing modes of operation. In other words, as far as condensation removal from the fin surfaces is concerned, the 10 fin per inch fin pitch of the VY coils results in a fin orientation that is sufficiently close to vertical as to make differences in condensation heat transfer predictions negligible.

Attachment L to
Proto-Power Calculation
97-199
Revision A

COMED NUCLEAR DESIGN INFORMATION TRANSMITTAL

☒ SAFETY-RELATED
☐ NON-SAFETY-RELATED
☐ REGULATORY RELATED

Originating Organization
Section: SE
Company: ComEd

NDIT No.: LS-0847
Upgrade: 0
Page 1 of 2

Station: LaSalle County Units: 1,2
Design Change Authority No N/A

System: VY

To: P hilpot, Lloyd. Proto-Power

Subject:
Dimensional Verification for Tubing and Fins for Coolers 1(2)VY03A and 1(2)VY04A.

Miller, William J. Preparer	System Engineer Position	William J Miller Signature	7/6/98 Date
Friedrich, Rich Reviewer	Engineer Position	Rich Friedrich Signature	7/6/98 Date
hall, Rich Approver	DE- Mech. Supv. Position	Richard Hall Signature	7/6/98 Date

Status of Information: ☒ Approved for Use ☐ Unverified ☐ Engineering Judgement
Verification Method N/A
Schedule:

Purpose of Issuance
Transmittal of Dimensions to Proto-Power for Heat Exchanger analysis.

Source of Information
Walkdown performed on the 2VY03A and 2VY04A coolers performed by W. Miller (System Engineering) and R. Friedrick (Design Engineering) on 7/3/98.

Description of Information
The following measurements were obtained for the 2VY03A and 2VY04A room coolers at the request of Proto Power Corporation. These conditions were obtained at ambient conditions with the systems shutdown. Attached is a copy of a sketch for each cooler that provides dimensions obtained in the field.

The following information was obtained for the 2VY03A cooler

Tube outside diameter:	0.672 inches
Fin Height:	1 452 inches
Transverse Tube Pitch.	1.410 Inches
Effective Finned Tube Length:	108 inches (dimension is based on 111 inches from the inside of the furthest separated tube support "end" plates, which includes three - 1 inch tube support plates between the end plates)

The following information was obtained for the 2VY04A cooler

Distribution: SEAG
Szumski, Daniel R. - ComEd, SES-BOP
Wilhelmsen, George R. - ComEd, SES-BOP

COMED NUCLEAR DESIGN INFORMATION TRANSMITTAL

☒ SAFETY-RELATED	Originating Organization	NDIT No.: LS-0847
☐ NON-SAFETY-RELATED	Section: SE	Upgrade: 0
☐ REGULATORY RELATED	Company: ComEd	Page 2 of 2

Tube outside diameter.	0.675 inches
Fin Height:	1.347 inches
Transverse Tube Pitch:	1.370 inches

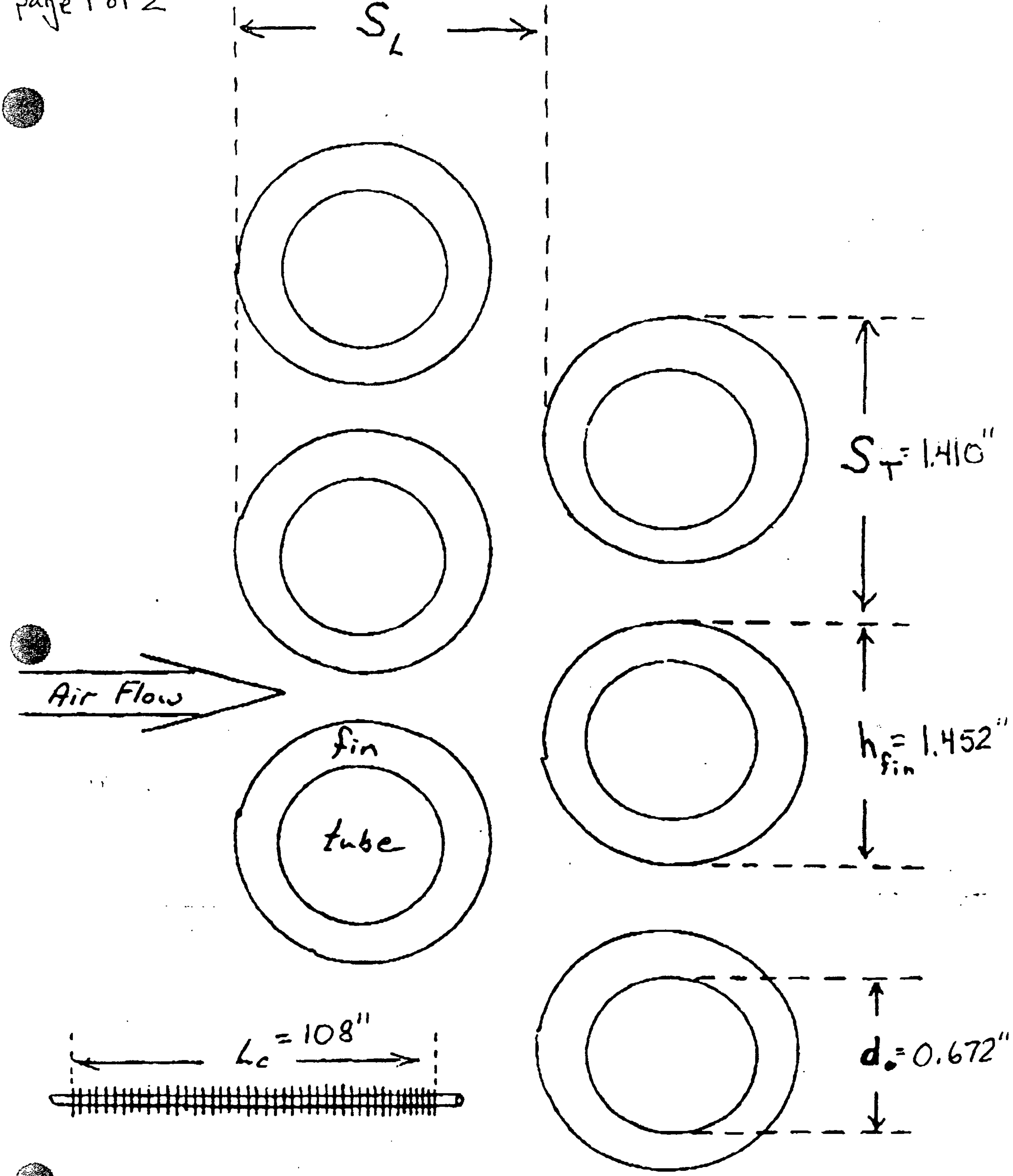
Effective Finned Tube Length: 105 inches (dimension is based on 108 inches from the inside of the furthest separated tube support "end" plates. which include three - 1 inch tube support plates between the end plates).

The first three measurement for each cooler were taken with a calibrated set of calipers (MMD Id No 7140, calibration due 2/99). The Effective Finned Tube Length was taken with a metal tape measure. The uncertainities for these measurements are based on engineering best estimates for the measurement techiniques used and are as stated in NDIT LS-0835 dated 6/19/98. Each cooler appeared to have staggered rows of tubes. The transverse tube pitch was variable for the various individual fins and the above dimension is considered typical.

Attachment 1 contains two sheets with sketches of the identical dimensions provided above.

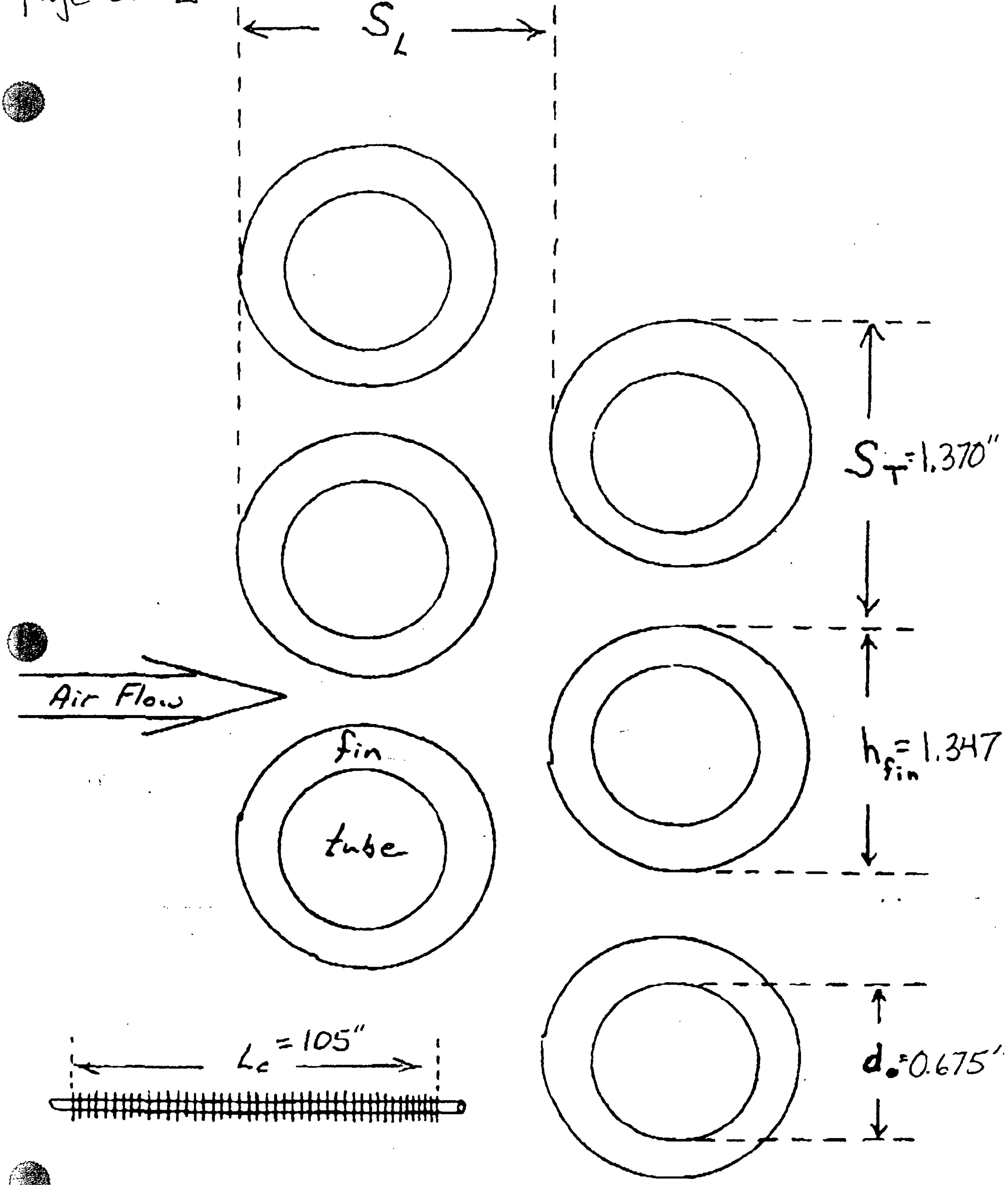
NDIT LS-0847. Page 2 of 2 end. Attached - 2 pages of sketch.

Attachment 1
page 1 of 2

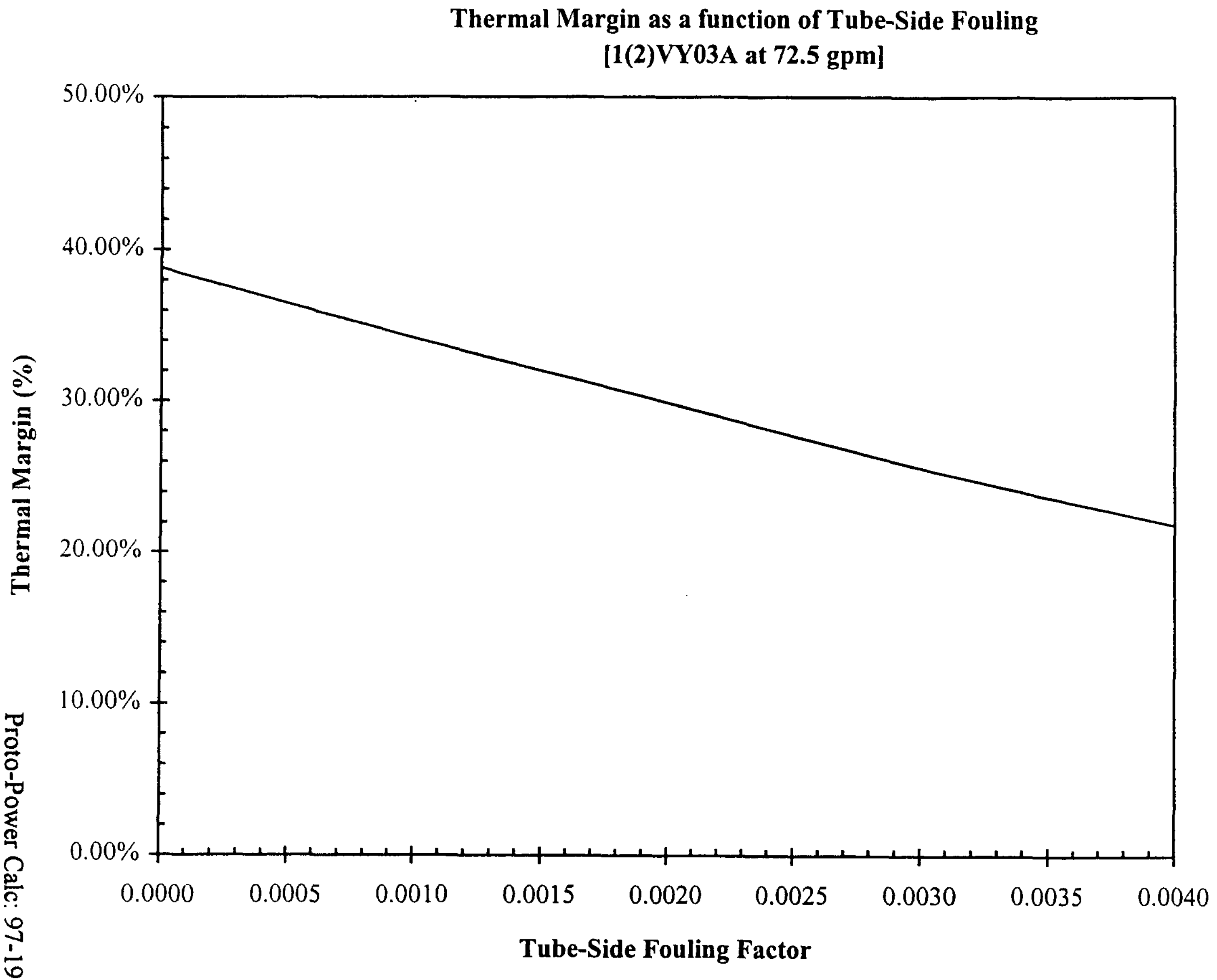


Attachment 1
Page 2 of 2

2VY04A



Attachment M to
Proto-Power Calculation
97-199
Revision A



Proto-Power Calc: 97-199
Attachment: M
Rev: A Page 2 of 17

ComEd -- LaSalle
Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
Fouling Sensitivity: Tube f = 0.0000

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	28,185.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

Fouling Sensitivity: Tube f = 0.0000

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,153.08	36,050.35
Inlet Temperature (°F)	148.00	100.00
Outlet Temperature (°F)	109.52	127.84
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.00200000
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	10,532.34
LMTD	
Total Heat Transferred (BTU/hr)	1,002,563
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	1,002,563
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,153.08	36,050.35
Inlet Temperature (°F)	148.00	123.96
Outlet Temperature (°F)	142.64	127.84
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	145.32	125.90
Skin Temperature (°F)	129.02	128.72
Velocity ***	4,218.88	2.24
Reynold's Number	940**	17,080
Prandtl Number	0.7254	3.4236
Bulk Visc (lbm/ft·hr)	0.0491	1.2749
Skin Visc (lbm/ft·hr)		1.2430
Density (lbm/ft³)	0.0621	61.6179
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0163	0.3720

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	841.25
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.91
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.00200000
U Overall (BTU/hr·ft²·°F)	6.89
Effective Area (ft²)	1,053.23
LMTD	19.24
Total Heat Transferred (BTU/hr)	139,692
Surface Effectiveness (Eta)	0.9217
Sensible Heat Transferred (BTU/hr)	139,692
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

ComEd -- LaSalle
Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
Fouling Sensitivity: Tube f = 0.0010

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001000
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	28,125.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Fouling Sensitivity: Tube f = 0.0010

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,931.36	36,050.35
Inlet Temperature (°F)	148.00	100.00
Outlet Temperature (°F)	110.72	126.91
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.01967103
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	10,532.34
LMTD	
Total Heat Transferred (BTU/hr)	969,164
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	969,164
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,931.36	36,050.35
Inlet Temperature (°F)	148.00	123.27
Outlet Temperature (°F)	142.97	126.91
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	145.48	125.09
Skin Temperature (°F)	130.23	127.73
Velocity ***	4,209.90	2.23
Reynold's Number	938**	16,954
Prandtl Number	0.7253	3.4514
Bulk Visc (lbm/ft·hr)	0.0491	1.2844
Skin Visc (lbm/ft·hr)		1.2540
Density (lbm/ft³)	0.0621	61.6311
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0163	0.3717

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	837.78
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.90
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.01967103
U Overall (BTU/hr·ft²·°F)	6.14
Effective Area (ft²)	1,053.23
LMTD	20.24
Total Heat Transferred (BTU/hr)	130,852
Surface Effectiveness (Eta)	0.9218
Sensible Heat Transferred (BTU/hr)	130,852
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
Fouling Sensitivity: Tube f = 0.0020

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.002000
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	28,070.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

16:17:19 **PROTO-HX 3.01 by Proto-Power Corporation (SN#PHX-0000)** 07/06/98

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Fouling Sensitivity: Tube f = 0.0020

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,728.12	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	111.85	126.02	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	10,532.34
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	938,124
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	938,124
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,728.12	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	834.45
Inlet Temperature (°F)	148.00	122.59	j Factor	0.0071
Outlet Temperature (°F)	143.24	126.02	Air-Side ho (BTU/hr·ft²·°F)	8.89
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	145.62	124.30		
Skin Temperature (°F)	131.24	126.80	U Overall (BTU/hr·ft²·°F)	5.53
Velocity ***	4,201.67	2.23	Effective Area (ft²)	1,053.23
Reynold's Number	936**	16,832	LMTD	21.19
Prandtl Number	0.7253	3.4788	Total Heat Transferred (BTU/hr)	123,422
Bulk Visc (lbm/ft·hr)	0.0491	1.2936		
Skin Visc (lbm/ft·hr)		1.2646	Surface Effectiveness (Eta)	0.9219
Density (lbm/ft³)	0.0621	61.6438	Sensible Heat Transferred (BTU/hr)	123,422
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3714	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Fouling Sensitivity: Tube f = 0.0030

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.003000
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
Fouling Sensitivity: Tube f = 0.0030

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	28,015.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

16:19:46 **PROTO-HX 3.01 by Proto-Power Corporation (SN#PHX-0000)** 07/06/98

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Fouling Sensitivity: Tube f = 0.0030

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,524.88	36,050.35	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	112.97	125.22	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.05501310
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	10,532.34
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	907,127
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	907,127
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,524.88	36,050.35	Tube-Side hi (BTU/hr·ft^2·°F)	831.46
Inlet Temperature (°F)	148.00	121.98	j Factor	0.0071
Outlet Temperature (°F)	143.49	125.22	Air-Side ho (BTU/hr·ft^2·°F)	8.88
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.05501310
Average Temp (°F)	145.75	123.60		
Skin Temperature (°F)	132.13	125.97	U Overall (BTU/hr·ft^2·°F)	5.03
Velocity ***	4,193.44	2.23	Effective Area (ft^2)	1,053.23
Reynold's Number	934**	16,723	LMTD	22.04
Prandtl Number	0.7253	3.5035	Total Heat Transferred (BTU/hr)	116,793
Bulk Visc (lbm/ft·hr)	0.0491	1.3021		
Skin Visc (lbm/ft·hr)		1.2741	Surface Effectiveness (Eta)	0.9220
Density (lbm/ft^3)	0.0620	61.6551	Sensible Heat Transferred (BTU/hr)	116,793
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3712	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

16:23:55 **PROTO-HX 3.01 by Proto-Power Corporation (SN#PHX-0000)** 07/06/98
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Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
Fouling Sensitivity: Tube f = 0.0040

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.004000
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Fouling Sensitivity: Tube f = 0.0040

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	27,967.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Fouling Sensitivity: Tube f = 0.0040

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,347.50	36,050.35	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	113.96	124.42	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.07268414
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	10,532.34
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	879,956
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	879,956
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,347.50	36,050.35	Tube-Side hi (BTU/hr·ft^2·°F)	828.42
Inlet Temperature (°F)	148.00	121.33	j Factor	0.0071
Outlet Temperature (°F)	143.70	124.42	Air-Side ho (BTU/hr·ft^2·°F)	8.87
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.07268414
Average Temp (°F)	145.85	122.88		
Skin Temperature (°F)	132.88	125.14	U Overall (BTU/hr·ft^2·°F)	4.62
Velocity ***	4,186.25	2.23	Effective Area (ft^2)	1,053.23
Reynold's Number	933**	16,612	LMTD	22.87
Prandtl Number	0.7253	3.5291	Total Heat Transferred (BTU/hr)	111,227
Bulk Visc (lbm/ft·hr)	0.0491	1.3108		
Skin Visc (lbm/ft·hr)		1.2838	Surface Effectiveness (Eta)	0.9220
Density (lbm/ft^3)	0.0620	61.6665	Sensible Heat Transferred (BTU/hr)	111,227
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3710	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment N to
Proto-Power Calculation
97-199
Revision A

Proto-HX Model Database

Saved on attached disk as:

Name: vy-03a.phx

Size: 1,277,952 bytes

Date: 7/6/98

Time: 6:21:52 pm

EXHIBIT A
(Page 4 of 4)

CALCULATION NO. 97-199 Rev B	Attachment O	PAGE NO. 01 of 01

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REVISION NO.	B			

CALCULATION NO. 97-199	Rev. B	Project No:	PAGE NO. P1

ATTACHMENT P

1.0 PURPOSE/OBJECTIVE

1.1 The purpose of this revision is to perform sensitivity computer calculations for the subject air cooler using reduced air inlet flow rates. This information may be used in the future for assessments of system performance in cases where air flow through this cooler may be slightly below the intended design values. Cases involving a 5% reduction and 10% reduction in inlet air volumetric flow will be calculated so that effect on heat transfer rate (Btu/hr) can be assessed. The existing computer model for the air cooling coil 1(2)VY03A generated in Revision A of this calculation will be used for this revision.

2.0 METHODOLOGY AND ACCEPTANCE CRITERIA

2.1 The methodology for this calculation involves the following activities:

- Utilize approved Proto-Hx software, 1(2)VY03A cooling coil model (generated in Revision A of this calculation), to calculate the heat exchanger performance with reductions in inlet air volumetric flow of 5% and 10% (two cases).

2.2 The acceptance criteria for this calculation is the following:

- There is no specific acceptance criteria as the purpose of this calculation is merely to predict additional data points for heat rejection capability based on reduced air inlet flow values.

3.0 ASSUMPTIONS

3.1 There are no assumptions within this calculation.

ATTACHMENT P

4.0 DESIGN INPUT

The design inputs to this calculation are the following:

4.1 Proto-Hx, Thermal Performance model for the LaSalle 1(2)VY03A cooling coil model, an approved calculational computer model generated in Revision A of this calculation.

4.2 Verification of PC Installation of Proto-Hx Version 3.00 an approved Computer Program (Reference 5.2).

5.0 REFERENCES

5.1 Proto-Hx, Version 3.00 and User Documentation – 1996

5.2 Calculation L-002210, Rev. 0, dated 11-18-98, Verification of PC Installation of Proto-Hx Version 3.00. (ComEd PC #507943)

ATTACHMENT P

6.0 CALCULATIONS

The existing Proto-Hx Model for this cooling coil, has adjusted design fouling factors of. Air Side=0.002 and Tube Side=0.002, this is acceptable and conservative for use in this sensitivity study, since the design values for these parameters are Air Side=0 and Tube Side=0.0015 (per Table 2 of this calculation). The cooling water flow rate used is 72.5 gpm, which is a limiting value, per Section 7.3 of this calculation.

Additional computer runs were made to evaluate cases of reduced air flow entering the cooler as follows:

a) Benchmark case (Run No. 1) using the above indicated fouling factors and the tube side flow rate= 72.5 gpm. Air flow into the cooler is 28,070 acfm (identical to fouling sensitivity case in Attachment M). The other input extrapolation data, e.g. tube inlet temperature, air inlet temperature, relative humidity, and atmospheric pressure are not altered. This computer run yielded identical results to the referenced Attachment M case indicating the model is working acceptably.

Since the VY fan is on the discharge side of the cooling coil, it is desirable to calculate the volumetric air flow on the discharge side of the coil. This is done by taking the exiting air-side mass flow given by Proto-Hx (from Row 10 of the coil), using the outlet density given by Proto-Hx convert to a volumetric flow (acfm).

103,728 (lbm/hr) / 0.0655 (lbm/ft^3) x 60 (min./hr) = 26,394 acfm. say 26,400 acfm

b) 5% reduction in inlet air flow (Run No. 2): Inlet air flow = 28,070 acfm – 5% = 26,666 acfm. This is the only input value changed for this case. The coil outlet flow is calculated as follows:

98,540 (lbm/hr) / 0.0656 (lbm/ft^3) x 60 (min./hr) = 25,036 acfm. say 25,000 acfm

c) 10% reduction in inlet air flow (Run No. 3): Inlet air flow = 28,070 acfm – 10% = 25,263 acfm. This is the only input value changed for this case.

93,355 (lbm/hr) / 0.0657 (lbm/ft^3) x 60 (min./hr) = 23,682 acfm. say 23,700 acfm

CALCULATION NO. 97-199	Rev. B	Project No:	PAGE NO. P4

ATTACHMENT P

7.0 SUMMARY AND CONCLUSIONS

Following is a summary of the results based on the input inlet air flow values showing the predicted heat rejection:

Air Flow Reduction	Inlet Air Flow	Outlet Air Flow	Total Heat Transferred
base	28,070 acfm	26,400 acfm	938,124 Btu/hr
5%	26,666 acfm	25,000 acfm	909,799 Btu/hr
10%	25,263 acfm	23,700 acfm	878,267 Btu/hr

Based on Table 1 of this calculation, the required heat transfer rate for this cooler is 722,217 Btu/hr. As expected, the reduction in air inlet flow reduces the amount of heat transfer, however the calculated values are still well above the required heat transfer rate noted.

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Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
Benchmark Case w/Service f=0.002

RUN No. 1

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.002000
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Run No. 1

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	28,070.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

Run No. 1

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,728.12	36,050.35	Tube-Side hi (BTU/hr·ft^{2}·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	111.85	126.02	Air-Side ho (BTU/hr·ft^{2}·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft^{2}·°F/BTU)	0.03734207
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^{2}·°F)	
Velocity ***			Effective Area (ft^{2})	10,532.34
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	938,124 ←
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^{3})			Sensible Heat Transferred (BTU/hr)	938,124
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,728.12	36,050.35	Tube-Side hi (BTU/hr·ft^{2}·°F)	834.45
Inlet Temperature (°F)	148.00	122.59	j Factor	0.0071
Outlet Temperature (°F)	143.24	126.02	Air-Side ho (BTU/hr·ft^{2}·°F)	8.89
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^{2}·°F/BTU)	0.03734207
Average Temp (°F)	145.62	124.30		
Skin Temperature (°F)	131.24	126.80	U Overall (BTU/hr·ft^{2}·°F)	5.53
Velocity ***	4,201.67	2.23	Effective Area (ft^{2})	1,053.23
Reynold's Number	936**	16,832	LMTD	21.19
Prandtl Number	0.7253	3.4788	Total Heat Transferred (BTU/hr)	123,422
Bulk Visc (lbm/ft·hr)	0.0491	1.2936		
Skin Visc (lbm/ft·hr)		1.2646	Surface Effectiveness (Eta)	0.9219
Density (lbm/ft^{3})	0.0621	61.6438	Sensible Heat Transferred (BTU/hr)	123,422
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3714	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft^{2}), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Benchmark Case w/Service f=0.002

Run No. 1

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,728.12	36,050.35	Tube-Side hi (BTU/hr·ft^2·°F)	820.85
Inlet Temperature (°F)	143.24	119.38	j Factor	0.0071
Outlet Temperature (°F)	138.79	122.59	Air-Side ho (BTU/hr·ft^2·°F)	8.87
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
Average Temp (°F)	141.02	120.98		
Skin Temperature (°F)	127.51	123.36	U Overall (BTU/hr·ft^2·°F)	5.51
Velocity ***	4,201.67	2.23	Effective Area (ft^2)	1,053.23
Reynold's Number	942**	16,322	LMTD	19.91
Prandtl Number	0.7258	3.5979	Total Heat Transferred (BTU/hr)	115,582
Bulk Visc (lbm/ft·hr)	0.0488	1.3341		
Skin Visc (lbm/ft·hr)		1.3049	Surface Effectiveness (Eta)	0.9220
Density (lbm/ft^3)	0.0625	61.6964	Sensible Heat Transferred (BTU/hr)	115,582
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0162	0.3704	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,728.12	36,050.35	Tube-Side hi (BTU/hr·ft^2·°F)	808.06
Inlet Temperature (°F)	138.79	116.37	j Factor	0.0071
Outlet Temperature (°F)	134.62	119.38	Air-Side ho (BTU/hr·ft^2·°F)	8.85
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
Average Temp (°F)	136.70	117.87		
Skin Temperature (°F)	124.03	120.14	U Overall (BTU/hr·ft^2·°F)	5.49
Velocity ***	4,201.67	2.23	Effective Area (ft^2)	1,053.23
Reynold's Number	947**	15,849	LMTD	18.72
Prandtl Number	0.7261	3.7157	Total Heat Transferred (BTU/hr)	108,279
Bulk Visc (lbm/ft·hr)	0.0485	1.3739		
Skin Visc (lbm/ft·hr)		1.3447	Surface Effectiveness (Eta)	0.9222
Density (lbm/ft^3)	0.0630	61.7443	Sensible Heat Transferred (BTU/hr)	108,279
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0161	0.3693	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Benchmark Case w/Service f=0.002

Run No. 1

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,728.12	36,050.35
Inlet Temperature (°F)	134.62	113.55
Outlet Temperature (°F)	130.71	116.37
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	132.66	114.96
Skin Temperature (°F)	120.76	117.11
Velocity ***	4,201.67	2.23
Reynold's Number	952**	15,410
Prandtl Number	0.7265	3.8319
Bulk Visc (lbm/ft·hr)	0.0483	1.4130
Skin Visc (lbm/ft·hr)		1.3839
Density (lbm/ft³)	0.0634	61.7881
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3683

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	796.02
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.83
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.48
Effective Area (ft²)	1,053.23
LMTD	17.59
Total Heat Transferred (BTU/hr)	101,473
Surface Effectiveness (Eta)	0.9224
Sensible Heat Transferred (BTU/hr)	101,473
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,728.12	36,050.35
Inlet Temperature (°F)	130.71	110.91
Outlet Temperature (°F)	127.04	113.55
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	128.87	112.23
Skin Temperature (°F)	117.70	114.28
Velocity ***	4,201.67	2.23
Reynold's Number	957**	15,003
Prandtl Number	0.7268	3.9463
Bulk Visc (lbm/ft·hr)	0.0480	1.4514
Skin Visc (lbm/ft·hr)		1.4224
Density (lbm/ft³)	0.0638	61.8281
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3673

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	784.69
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.81
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.46
Effective Area (ft²)	1,053.23
LMTD	16.54
Total Heat Transferred (BTU/hr)	95,126
Surface Effectiveness (Eta)	0.9225
Sensible Heat Transferred (BTU/hr)	95,126
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Benchmark Case w/Service f=0.002

Run No. 1

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,728.12	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	774.02
Inlet Temperature (°F)	127.04	108.43	j Factor	0.0070
Outlet Temperature (°F)	123.60	110.91	Air-Side ho (BTU/hr·ft²·°F)	8.80
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	125.32	109.67		
Skin Temperature (°F)	114.82	111.62	U Overall (BTU/hr·ft²·°F)	5.44
Velocity ***	4,201.67	2.23	Effective Area (ft²)	1,053.23
Reynold's Number	961**	14,624	LMTD	15.56
Prandtl Number	0.7270	4.0586	Total Heat Transferred (BTU/hr)	89,203
Bulk Visc (lbm/ft·hr)	0.0478	1.4889		
Skin Visc (lbm/ft·hr)		1.4602	Surface Effectiveness (Eta)	0.9226
Density (lbm/ft³)	0.0642	61.8646	Sensible Heat Transferred (BTU/hr)	89,203
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0158	0.3664	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,728.12	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	763.98
Inlet Temperature (°F)	123.60	106.11	j Factor	0.0070
Outlet Temperature (°F)	120.38	108.43	Air-Side ho (BTU/hr·ft²·°F)	8.78
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	121.99	107.27		
Skin Temperature (°F)	112.13	109.12	U Overall (BTU/hr·ft²·°F)	5.43
Velocity ***	4,201.67	2.23	Effective Area (ft²)	1,053.23
Reynold's Number	965**	14,272	LMTD	14.63
Prandtl Number	0.7273	4.1689	Total Heat Transferred (BTU/hr)	83,674
Bulk Visc (lbm/ft·hr)	0.0476	1.5256		
Skin Visc (lbm/ft·hr)		1.4972	Surface Effectiveness (Eta)	0.9227
Density (lbm/ft³)	0.0645	61.8981	Sensible Heat Transferred (BTU/hr)	83,674
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0157	0.3655	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
Benchmark Case w/Service f=0.002

Run No. 1

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,728.12	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	754.53
Inlet Temperature (°F)	120.38	103.93	j Factor	0.0070
Outlet Temperature (°F)	117.35	106.11	Air-Side ho (BTU/hr·ft²·°F)	8.77
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	118.86	105.02		
Skin Temperature (°F)	109.60	106.78	U Overall (BTU/hr·ft²·°F)	5.42
Velocity ***	4,201.67	2.22	Effective Area (ft²)	1,053.23
Reynold's Number	969**	13,945	LMTD	13.77
Prandtl Number	0.7275	4.2767	Total Heat Transferred (BTU/hr)	78,509
Bulk Visc (lbm/ft·hr)	0.0474	1.5615		
Skin Visc (lbm/ft·hr)		1.5334	Surface Effectiveness (Eta)	0.9229
Density (lbm/ft³)	0.0649	61.9287	Sensible Heat Transferred (BTU/hr)	78,509
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0157	0.3647	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	103,728.12	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	745.64
Inlet Temperature (°F)	117.35	101.88	j Factor	0.0070
Outlet Temperature (°F)	114.51	103.93	Air-Side ho (BTU/hr·ft²·°F)	8.75
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	115.93	102.91		
Skin Temperature (°F)	107.22	104.57	U Overall (BTU/hr·ft²·°F)	5.40
Velocity ***	4,201.67	2.22	Effective Area (ft²)	1,053.23
Reynold's Number	973**	13,640	LMTD	12.95
Prandtl Number	0.7277	4.3821	Total Heat Transferred (BTU/hr)	73,683
Bulk Visc (lbm/ft·hr)	0.0472	1.5964		
Skin Visc (lbm/ft·hr)		1.5687	Surface Effectiveness (Eta)	0.9230
Density (lbm/ft³)	0.0652	61.9568	Sensible Heat Transferred (BTU/hr)	73,683
Cp (BTU/lbm·°F)	0.2402	0.9990	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3639	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

Benchmark Case w/Service f=0.002

Run No. 1

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	103,728.12	36,050.35
Inlet Temperature (°F)	114.51	99.96
Outlet Temperature (°F)	111.85	101.88
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	113.18	100.92
Skin Temperature (°F)	104.99	102.51
Velocity ***	4,201.67	2.22
Reynold's Number	977**	13,356
Prandtl Number	0.7278	4.4848
Bulk Visc (lbm/ft·hr)	0.0470	1.6303
Skin Visc (lbm/ft·hr)		1.6031
Density (lbm/ft³)	0.0655	61.9826
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0155	0.3631

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	737.27
j Factor	0.0070
Air-Side ho (BTU/hr·ft²·°F)	8.74
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.39
Effective Area (ft²)	1,053.23
LMTD	12.19
Total Heat Transferred (BTU/hr)	69,171
Surface Effectiveness (Eta)	0.9231
Sensible Heat Transferred (BTU/hr)	69,171
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

5% Reduction in Air Inlet Vol. Flow

Run No. 2

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.002000
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

5% Reduction in Air Inlet Vol. Flow

Run No. 2

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date
Air Flow (acfm)
Air Dry Bulb Temp In (°F)
Air Dry Bulb Temp Out (°F)
Relative Humidity In (%)
Relative Humidity Out (%)
Wet Bulb Temp In (°F)
Wet Bulb Temp Out (°F)
Atmospheric Pressure
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)
Condensate Temperature (°F)

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	26,666.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

5% Reduction in Air Inlet Vol. Flow

Run No. 2

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	98,539.87	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	111.09	125.22	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	10,532.34
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	909,799 ←
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	909,799
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	98,539.87	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	831.19
Inlet Temperature (°F)	148.00	121.76	j Factor	0.0072
Outlet Temperature (°F)	142.95	125.22	Air-Side ho (BTU/hr·ft²·°F)	8.59
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	145.47	123.49		
Skin Temperature (°F)	130.50	126.02	U Overall (BTU/hr·ft²·°F)	5.41
Velocity ***	3,991.51	2.23	Effective Area (ft²)	1,053.23
Reynold's Number	890**	16,706	LMTD	21.85
Prandtl Number	0.7253	3.5073	Total Heat Transferred (BTU/hr)	124,529
Bulk Visc (lbm/ft·hr)	0.0491	1.3034		
Skin Visc (lbm/ft·hr)		1.2735	Surface Effectiveness (Eta)	0.9242
Density (lbm/ft³)	0.0621	61.6568	Sensible Heat Transferred (BTU/hr)	124,529
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3712	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

5% Reduction in Air Inlet Vol. Flow

Run No. 2

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	98,539.87	36,050.35	Tube-Side hi (BTU/hr·ft^2·°F)	817.50
Inlet Temperature (°F)	142.95	118.55	j Factor	0.0072
Outlet Temperature (°F)	138.27	121.76	Air-Side ho (BTU/hr·ft^2·°F)	8.57
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
Average Temp (°F)	140.61	120.16		
Skin Temperature (°F)	126.69	122.54	U Overall (BTU/hr·ft^2·°F)	5.39
Velocity ***	3,991.51	2.23	Effective Area (ft^2)	1,053.23
Reynold's Number	895**	16,196	LMTD	20.32
Prandtl Number	0.7258	3.6286	Total Heat Transferred (BTU/hr)	115,433
Bulk Visc (lbm/ft·hr)	0.0488	1.3445		
Skin Visc (lbm/ft·hr)		1.3148	Surface Effectiveness (Eta)	0.9244
Density (lbm/ft^3)	0.0626	61.7092	Sensible Heat Transferred (BTU/hr)	115,433
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0161	0.3701	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	98,539.87	36,050.35	Tube-Side hi (BTU/hr·ft^2·°F)	804.75
Inlet Temperature (°F)	138.27	115.58	j Factor	0.0072
Outlet Temperature (°F)	133.92	118.55	Air-Side ho (BTU/hr·ft^2·°F)	8.55
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.03734207
Average Temp (°F)	136.09	117.07		
Skin Temperature (°F)	123.16	119.31	U Overall (BTU/hr·ft^2·°F)	5.37
Velocity ***	3,991.51	2.23	Effective Area (ft^2)	1,053.23
Reynold's Number	900**	15,727	LMTD	18.91
Prandtl Number	0.7262	3.7473	Total Heat Transferred (BTU/hr)	107,047
Bulk Visc (lbm/ft·hr)	0.0485	1.3845		
Skin Visc (lbm/ft·hr)		1.3552	Surface Effectiveness (Eta)	0.9246
Density (lbm/ft^3)	0.0631	61.7566	Sensible Heat Transferred (BTU/hr)	107,047
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0160	0.3690	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

5% Reduction in Air Inlet Vol. Flow

Run No. 2

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	98,539.87	36,050.35
Inlet Temperature (°F)	133.92	112.82
Outlet Temperature (°F)	129.89	115.58
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	131.91	114.20
Skin Temperature (°F)	119.89	116.32
Velocity ***	3,991.51	2.23
Reynold's Number	905**	15,297
Prandtl Number	0.7265	3.8631
Bulk Visc (lbm/ft·hr)	0.0482	1.4235
Skin Visc (lbm/ft·hr)		1.3946
Density (lbm/ft³)	0.0635	61.7993
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3680

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	792.86
j Factor	0.0072
Air-Side ho (BTU/hr·ft²·°F)	8.53
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.36
Effective Area (ft²)	1,053.23
LMTD	17.60
Total Heat Transferred (BTU/hr)	99,311
Surface Effectiveness (Eta)	0.9247
Sensible Heat Transferred (BTU/hr)	99,311
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	98,539.87	36,050.35
Inlet Temperature (°F)	129.89	110.26
Outlet Temperature (°F)	126.15	112.82
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	128.02	111.54
Skin Temperature (°F)	116.85	113.53
Velocity ***	3,991.51	2.23
Reynold's Number	910**	14,901
Prandtl Number	0.7268	3.9760
Bulk Visc (lbm/ft·hr)	0.0480	1.4613
Skin Visc (lbm/ft·hr)		1.4328
Density (lbm/ft³)	0.0639	61.8380
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3671

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	781.79
j Factor	0.0072
Air-Side ho (BTU/hr·ft²·°F)	8.52
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.34
Effective Area (ft²)	1,053.23
LMTD	16.38
Total Heat Transferred (BTU/hr)	92,171
Surface Effectiveness (Eta)	0.9248
Sensible Heat Transferred (BTU/hr)	92,171
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec): Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

5% Reduction in Air Inlet Vol. Flow

Run No. 2

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	98,539.87	36,050.35
Inlet Temperature (°F)	126.15	107.89
Outlet Temperature (°F)	122.68	110.26
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	124.42	109.07
Skin Temperature (°F)	114.02	110.95
Velocity ***	3,991.51	2.23
Reynold's Number	914**	14,537
Prandtl Number	0.7271	4.0856
Bulk Visc (lbm/ft·hr)	0.0478	1.4979
Skin Visc (lbm/ft·hr)		1.4700
Density (lbm/ft³)	0.0643	61.8730
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3662

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	771.48
j Factor	0.0072
Air-Side ho (BTU/hr·ft²·°F)	8.50
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.33
Effective Area (ft²)	1,053.23
LMTD	15.25
Total Heat Transferred (BTU/hr)	85,575
Surface Effectiveness (Eta)	0.9250
Sensible Heat Transferred (BTU/hr)	85,575
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	98,539.87	36,050.35
Inlet Temperature (°F)	122.68	105.68
Outlet Temperature (°F)	119.46	107.89
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	121.07	106.78
Skin Temperature (°F)	111.40	108.54
Velocity ***	3,991.51	2.22
Reynold's Number	918**	14,201
Prandtl Number	0.7273	4.1919
Bulk Visc (lbm/ft·hr)	0.0476	1.5333
Skin Visc (lbm/ft·hr)		1.5060
Density (lbm/ft³)	0.0646	61.9048
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3654

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	761.86
j Factor	0.0072
Air-Side ho (BTU/hr·ft²·°F)	8.49
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.31
Effective Area (ft²)	1,053.23
LMTD	14.20
Total Heat Transferred (BTU/hr)	79,478
Surface Effectiveness (Eta)	0.9251
Sensible Heat Transferred (BTU/hr)	79,478
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils
5% Reduction in Air Inlet Vol. Flow

Run No. 2

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	98,539.87	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	752.91
Inlet Temperature (°F)	119.46	103.63	j Factor	0.0071
Outlet Temperature (°F)	116.46	105.68	Air-Side ho (BTU/hr·ft²·°F)	8.47
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	117.96	104.65		
Skin Temperature (°F)	108.96	106.31	U Overall (BTU/hr·ft²·°F)	5.30
Velocity ***	3,991.51	2.22	Effective Area (ft²)	1,053.23
Reynold's Number	922**	13,892	LMTD	13.23
Prandtl Number	0.7275	4.2946	Total Heat Transferred (BTU/hr)	73,840
Bulk Visc (lbm/ft·hr)	0.0474	1.5674		
Skin Visc (lbm/ft·hr)		1.5408	Surface Effectiveness (Eta)	0.9252
Density (lbm/ft³)	0.0650	61.9336	Sensible Heat Transferred (BTU/hr)	73,840
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3646	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	98,539.87	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	744.56
Inlet Temperature (°F)	116.46	101.72	j Factor	0.0071
Outlet Temperature (°F)	113.68	103.63	Air-Side ho (BTU/hr·ft²·°F)	8.46
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	115.07	102.68		
Skin Temperature (°F)	106.70	104.23	U Overall (BTU/hr·ft²·°F)	5.29
Velocity ***	3,991.51	2.22	Effective Area (ft²)	1,053.23
Reynold's Number	926**	13,607	LMTD	12.32
Prandtl Number	0.7277	4.3938	Total Heat Transferred (BTU/hr)	68,623
Bulk Visc (lbm/ft·hr)	0.0472	1.6002		
Skin Visc (lbm/ft·hr)		1.5743	Surface Effectiveness (Eta)	0.9253
Density (lbm/ft³)	0.0653	61.9598	Sensible Heat Transferred (BTU/hr)	68,623
Cp (BTU/lbm·°F)	0.2402	0.9990	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3638	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

5% Reduction in Air Inlet Vol. Flow

Run No. 2

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	98,539.87	36,050.35
Inlet Temperature (°F)	113.68	99.95
Outlet Temperature (°F)	111.09	101.72
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	112.39	100.84
Skin Temperature (°F)	104.59	102.30
Velocity ***	3,991.51	2.22
Reynold's Number	929**	13,344
Prandtl Number	0.7279	4.4893
Bulk Visc (lbm/ft·hr)	0.0470	1.6318
Skin Visc (lbm/ft·hr)		1.6066
Density (lbm/ft³)	0.0656	61.9837
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0155	0.3631

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	736.78
j Factor	0.0071
Air-Side ho (BTU/hr·ft²·°F)	8.45
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.28
Effective Area (ft²)	1,053.23
LMTD	11.48
Total Heat Transferred (BTU/hr)	63,792
Surface Effectiveness (Eta)	0.9254
Sensible Heat Transferred (BTU/hr)	63,792
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Data Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

10% Reduction in Air Inlet Vol. Flow

Run No. 3

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	31,066.00 acfm	180.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	108.80 °F	117.70 °F
Outlet Wet Bulb Temp	84.00 °F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.002000
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	1,108,000
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY03A j = EXP[-2.5939 + -0.3438 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.452
Number of Coils Per Unit	2
Number of Tube Rows	10
Number of Tubes Per Row	24.00
Active Tubes Per Row	24.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.400
Transverse Tube Pitch (in)	1.410
Number of Serpentines	1.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

10% Reduction in Air Inlet Vol. Flow

Run No. 3

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	72.50
Air Flow (acfm)	25,263.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

10% Reduction in Air Inlet Vol. Flow

RUN No. 3
PNJ 2/19/99

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	93,355.31	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	110.39	124.42	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	10,532.34
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	878,267 ←
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	878,267
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	93,355.31	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	827.94
Inlet Temperature (°F)	148.00	120.94	j Factor	0.0074
Outlet Temperature (°F)	142.64	124.42	Air-Side ho (BTU/hr·ft²·°F)	8.29
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	145.32	122.68		
Skin Temperature (°F)	129.74	125.24	U Overall (BTU/hr·ft²·°F)	5.29
Velocity ***	3,781.50	2.23	Effective Area (ft²)	1,053.23
Reynold's Number	843**	16,582	LMTD	22.49
Prandtl Number	0.7254	3.5361	Total Heat Transferred (BTU/hr)	125,278
Bulk Visc (lbm/ft·hr)	0.0491	1.3131		
Skin Visc (lbm/ft·hr)		1.2826	Surface Effectiveness (Eta)	0.9266
Density (lbm/ft³)	0.0621	61.6696	Sensible Heat Transferred (BTU/hr)	125,278
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3709	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

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Attachment P
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*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Run No.3

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,355.31	36,050.35
Inlet Temperature (°F)	142.64	117.75
Outlet Temperature (°F)	137.72	120.94
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	140.18	119.35
Skin Temperature (°F)	125.86	121.73
Velocity ***	3,781.50	2.23
Reynold's Number	848**	16,073
Prandtl Number	0.7258	3.6591
Bulk Visc (lbm/ft·hr)	0.0488	1.3548
Skin Visc (lbm/ft·hr)		1.3248
Density (lbm/ft³)	0.0626	61.7218
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3698

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	814.20
j Factor	0.0074
Air-Side ho (BTU/hr·ft²·°F)	8.27
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.27
Effective Area (ft²)	1,053.23
LMTD	20.70
Total Heat Transferred (BTU/hr)	114,868
Surface Effectiveness (Eta)	0.9268
Sensible Heat Transferred (BTU/hr)	114,868
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,355.31	36,050.35
Inlet Temperature (°F)	137.72	114.83
Outlet Temperature (°F)	133.20	117.75
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	135.46	116.29
Skin Temperature (°F)	122.30	118.51
Velocity ***	3,781.50	2.23
Reynold's Number	854**	15,610
Prandtl Number	0.7262	3.7782
Bulk Visc (lbm/ft·hr)	0.0485	1.3949
Skin Visc (lbm/ft·hr)		1.3656
Density (lbm/ft³)	0.0631	61.7683
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3688

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	801.53
j Factor	0.0073
Air-Side ho (BTU/hr·ft²·°F)	8.25
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.25
Effective Area (ft²)	1,053.23
LMTD	19.05
Total Heat Transferred (BTU/hr)	105,379
Surface Effectiveness (Eta)	0.9270
Sensible Heat Transferred (BTU/hr)	105,379
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

10% Reduction in Air Inlet Vol. Flow

Run No. 3

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,355.31	36,050.35
Inlet Temperature (°F)	133.20	112.14
Outlet Temperature (°F)	129.06	114.83
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	131.13	113.48
Skin Temperature (°F)	119.03	115.55
Velocity ***	3,781.50	2.23
Reynold's Number	858**	15,189
Prandtl Number	0.7266	3.8931
Bulk Visc (lbm/ft·hr)	0.0482	1.4336
Skin Visc (lbm/ft·hr)		1.4049
Density (lbm/ft³)	0.0636	61.8099
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3678

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	789.86
j Factor	0.0073
Air-Side ho (BTU/hr·ft²·°F)	8.23
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.24
Effective Area (ft²)	1,053.23
LMTD	17.54
Total Heat Transferred (BTU/hr)	96,720
Surface Effectiveness (Eta)	0.9271
Sensible Heat Transferred (BTU/hr)	96,720
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,355.31	36,050.35
Inlet Temperature (°F)	129.06	109.67
Outlet Temperature (°F)	125.26	112.14
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	127.16	110.91
Skin Temperature (°F)	116.02	112.83
Velocity ***	3,781.50	2.23
Reynold's Number	863**	14,807
Prandtl Number	0.7269	4.0038
Bulk Visc (lbm/ft·hr)	0.0479	1.4706
Skin Visc (lbm/ft·hr)		1.4428
Density (lbm/ft³)	0.0640	61.8471
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3669

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	779.10
j Factor	0.0073
Air-Side ho (BTU/hr·ft²·°F)	8.22
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.22
Effective Area (ft²)	1,053.23
LMTD	16.15
Total Heat Transferred (BTU/hr)	88,814
Surface Effectiveness (Eta)	0.9272
Sensible Heat Transferred (BTU/hr)	88,814
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

10% Reduction in Air Inlet Vol. Flow

Run No. 3

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,355.31	36,050.35
Inlet Temperature (°F)	125.26	107.41
Outlet Temperature (°F)	121.77	109.67
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	123.51	108.54
Skin Temperature (°F)	113.26	110.33
Velocity ***	3,781.50	2.23
Reynold's Number	867**	14,458
Prandtl Number	0.7272	4.1100
Bulk Visc (lbm/ft·hr)	0.0477	1.5060
Skin Visc (lbm/ft·hr)		1.4791
Density (lbm/ft³)	0.0644	61.8805
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0158	0.3660

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	769.18
j Factor	0.0073
Air-Side ho (BTU/hr·ft²·°F)	8.20
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.21
Effective Area (ft²)	1,053.23
LMTD	14.88
Total Heat Transferred (BTU/hr)	81,588
Surface Effectiveness (Eta)	0.9274
Sensible Heat Transferred (BTU/hr)	81,588
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,355.31	36,050.35
Inlet Temperature (°F)	121.77	105.33
Outlet Temperature (°F)	118.56	107.41
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	120.16	106.37
Skin Temperature (°F)	110.73	108.03
Velocity ***	3,781.50	2.22
Reynold's Number	871**	14,140
Prandtl Number	0.7274	4.2117
Bulk Visc (lbm/ft·hr)	0.0475	1.5399
Skin Visc (lbm/ft·hr)		1.5139
Density (lbm/ft³)	0.0647	61.9105
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3652

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	760.03
j Factor	0.0073
Air-Side ho (BTU/hr·ft²·°F)	8.19
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.19
Effective Area (ft²)	1,053.23
LMTD	13.71
Total Heat Transferred (BTU/hr)	74,979
Surface Effectiveness (Eta)	0.9275
Sensible Heat Transferred (BTU/hr)	74,979
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

10% Reduction in Air Inlet Vol. Flow

Run No. 3

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	93,355.31	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	751.60
Inlet Temperature (°F)	118.56	103.41	j Factor	0.0073
Outlet Temperature (°F)	115.60	105.33	Air-Side ho (BTU/hr·ft²·°F)	8.17
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	117.08	104.37		
Skin Temperature (°F)	108.39	105.92	U Overall (BTU/hr·ft²·°F)	5.18
Velocity ***	3,781.50	2.22	Effective Area (ft²)	1,053.23
Reynold's Number	875**	13,851	LMTD	12.63
Prandtl Number	0.7276	4.3088	Total Heat Transferred (BTU/hr)	68,931
Bulk Visc (lbm/ft·hr)	0.0473	1.5721		
Skin Visc (lbm/ft·hr)		1.5470	Surface Effectiveness (Eta)	0.9276
Density (lbm/ft³)	0.0651	61.9375	Sensible Heat Transferred (BTU/hr)	68,931
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3645	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

Extrapolation Calculation for Row 9(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	93,355.31	36,050.35	Tube-Side hi (BTU/hr·ft²·°F)	743.83
Inlet Temperature (°F)	115.60	101.65	j Factor	0.0073
Outlet Temperature (°F)	112.89	103.41	Air-Side ho (BTU/hr·ft²·°F)	8.16
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03734207
Average Temp (°F)	114.25	102.53		
Skin Temperature (°F)	106.25	103.97	U Overall (BTU/hr·ft²·°F)	5.17
Velocity ***	3,781.50	2.22	Effective Area (ft²)	1,053.23
Reynold's Number	878**	13,586	LMTD	11.65
Prandtl Number	0.7278	4.4012	Total Heat Transferred (BTU/hr)	63,393
Bulk Visc (lbm/ft·hr)	0.0471	1.6027		
Skin Visc (lbm/ft·hr)		1.5786	Surface Effectiveness (Eta)	0.9277
Density (lbm/ft³)	0.0654	61.9617	Sensible Heat Transferred (BTU/hr)	63,393
Cp (BTU/lbm·°F)	0.2402	0.9990	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3638	Heat to Condensate (BTU/hr)	

** Reynolds Number Outside Range of Equation Applicability

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

17:13:08 **PROTO-HX 3.00 by Proto-Power Corporation (SN#663-7371)** 02/18/99

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Calculation Report for: 1(2)VY03A - CSCS Equipment Area Cooling Coils

10% Reduction in Air Inlet Vol. Flow

Run No. 3

Extrapolation Calculation for Row 10(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	93,355.31	36,050.35
Inlet Temperature (°F)	112.89	100.03
Outlet Temperature (°F)	110.39	101.65
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	111.64	100.84
Skin Temperature (°F)	104.27	102.18
Velocity ***	3,781.50	2.22
Reynold's Number	881**	13,344
Prandtl Number	0.7279	4.4892
Bulk Visc (lbm/ft·hr)	0.0469	1.6317
Skin Visc (lbm/ft·hr)		1.6087
Density (lbm/ft³)	0.0657	61.9836
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0155	0.3631

** Reynolds Number Outside Range of Equation Applicability

Tube-Side hi (BTU/hr·ft²·°F)	736.66
j Factor	0.0073
Air-Side ho (BTU/hr·ft²·°F)	8.15
Tube Wall Resistance (hr·ft²·°F/BTU	0.00029413
Overall Fouling (hr·ft²·°F/BTU)	0.03734207
U Overall (BTU/hr·ft²·°F)	5.16
Effective Area (ft²)	1,053.23
LMTD	10.73
Total Heat Transferred (BTU/hr)	58,318
Surface Effectiveness (Eta)	0.9278
Sensible Heat Transferred (BTU/hr)	58,318
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

ATTACHMENT 2
Design Analysis Minor Revision Cover Sheet

Design Analysis (Minor Revision)
Last Page No. [6] Attachment A, A13

Analysis No.: [1] 97-198 **Revision:** [2] A03

Title: [3] VY Cooler Thermal Performance Model – 1(2)VY04A

EC/ECR No.: [4] 388666 **Revision:** [5] 000

Station(s): [7] LaSalle

Unit No.: [8] 01 & 02

Safety/QA Class: [9] SR

System Code(s): [10] VY

Is this Design Analysis Safeguards Information? [11] Yes ☐ No ☒ If yes, see SY-AA-101-106

Does this Design Analysis contain Unverified Assumptions? [12] Yes ☐ No ☒ If yes, ATI/AR#: N/A

This Design Analysis SUPERCEDES: [13] **N/A** **in its entirety.**

Description of Changes (list affected pages): [14]
This revision evaluates a maximum cooling water inlet temperature of 107 °F. The previous temperature that was evaluated was 104 °F. Affected pages are Pages 1 & 2 and Attachment A, Pages A1-A13.

Disposition of Changes: [15]
See attached pages. Changes are acceptable.

Preparer: [16] Sean Tanton (Print Name) Sean Tanton (Sign Name) 4/26/12 (Date)

Method of Review: [17] **Detailed Review** ☒ **Alternate Calculations** ☐ **Testing** ☐

Reviewer: [18] Steve Chon (Print Name) (Sign Name) 5/15/12 (Date)

Review Notes: [19] Independent review ☒ Peer review ☐

(For External Analyses Only)
External Approver: [20] NA (Print Name) (Sign Name) (Date)

Exelon Reviewer [21] NA (Print Name) (Sign Name) (Date)

Exelon Approver: [22] DAN SCHMIT (Print Name) DJSchmit (Sign Name) 5/17/12 (Date)

Purpose:
The purpose of this revision is to verify that the 1(2)VY04A coolers can remove the design heat load of 633,288 BTU/hr with a revised maximum cooling water temperature of 107 °F.

Assumptions:
There are no assumptions for this revision.

Inputs:
- Cooling water temperature = 107 °F (Reference 2)
- Air temperature = 148 °F (Reference 1)
- Water flow rate = 66.5 gpm (39.2 gpm front, 27.3 gpm back) (Reference 1)
- Air Flow rate = 27,075 cfm (Reference 1)
- Fouling factor = 0.02228812 hr·ft^2·°F/BTU (design fouling factor) (Reference 1)
- 1 tube plugged (5% tube plugging) (Reference 1)

References:
1. Design analysis 97-198, Rev. A, up to and including Revs A00 through A02
2. EC 388666, Rev. 000

Identification of Computer Programs:
The computer program used in this analysis is Proto HX version 4.01. This program has been validated per DTSQA tracking number EX0000103.

Method of Analysis / Numeric Analysis:
The existing heat exchanger model will be revised by changing the input of the "Tube Inlet Temp" from 104 °F to 107 °F. Because the 1(2)VY04A model consists of two separate models of the front and back portions of the cooler, the temperature, and relative humidity of the air exiting the front cooler are the inputs for the back cooler. The air flow rate is adjusted to match the mass flow rates between the two models. Because the fan for the coolers is at the exit of the cooler, the inlet air flow for the front cooler is iterated until the flow rate at the exit of the last row of the back cooler is approximately 27,075 cfm. The iteration process is detailed in section 6.7 of revision A00. The calculated input flows for the two coolers are shown on the last page of Attachment A.

Results / Conclusions:
The 1(2)VY04A coolers can remove the design heat load of 633,288 BTU/hr with the following conditions:
- 107 °F cooling water temperature
- 148 °F air temperature
- design fouling factor of 0.02228812 hr·ft^2·°F/BTU
- 1 tube plugged
- air flow rate of 27,075 cfm
- water flow rate of 66.5 gpm (39.2 gpm front, 27.3 gpm back)

The total heat removed at these conditions is 697,494 BTU/hr, which provides 10.13% thermal margin over the design heat load. This thermal margin is enough to account for the 9.5% model uncertainty shown in Attachment J and is acceptable. Note that a maximum fouling factor was not calculated as was done in previous revisions because it is not practical to set up test conditions that would allow accurate measurement of the fouling factor for these heat exchangers. The bounding fouling factor is the design fouling factor of 0.02228812 hr·ft^2·°F/BTU. This case is shown in Attachment A.

Attachments:
A. Data Report for 1(2)VY04A Front and Back (13 pgs)

04-26-2012 07:02:14 **PROTO-HX 4.01 by Proto-Power Corporation (SN#PHX-1002)**

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Data Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 - 148 °F air side, 27,075 cfm, 107 °F water side, 66.5 gpm, Design FF, 1 tube plugged

Air Coil Heat Exchanger Input Parameters

	Air-Side		Tube-Side	
Flow	33,546.00	acfm	118.00	gpm
Mass Flow	0.00	lbm/hr	0.00	lbm/hr
Dry Bulb (Inlet Temperature)	150.00	°F	105.00	°F
Inlet Wet Bulb Temperature	92.00	°F		
Inlet Relative Humidity	0.00	%		
Dry Bulb (Outlet Temperature)	0.00	°F	0.00	°F
Outlet Wet Bulb Temperature	0.00	°F		
Outlet Relative Humidity	0.00	%		

Tube Fluid Name	Fresh Water
Tube-Side Fouling	0.001500
Air-Side Fouling	0.000000
Design Q (BTU/hr)	
Atmospheric Pressure (psia)	14.315
Design Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Coil Flow Direction	Counter Flow
Fin Type	Circular Fins
Configuration (for Air-Side h)	LaSalle VY Cooler 04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	19.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 - 148 °F air side, 27,075 cfm, 107 °F water side, 66.5 gpm, Design FF, 1 tube plugged

Calculation Specifications

Constant Inlet Temperature Method Was Used

Extrapolation Was to User Specified Conditions

Design Fouling Factors Were Used

Test Data

Data Date
Air Flow (acfm)
Air Dry Bulb Temp In (°F)
Air Dry Bulb Temp Out (°F)
Relative Humidity In (%)
Relative Humidity Out (%)
Wet Bulb Temp In (°F)
Wet Bulb Temp Out (°F)
Atmospheric Pressure (psia)
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)
Condensate Temperature (°F)

Extrapolation Data

Tube Flow (gpm)	39.20
Air Flow (acfm)	28,317.00
Tube Inlet Temp (°F)	107.00
Air Inlet Temp (°F)	148.00
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure (psia)	14.315

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 - 148 °F air side, 27,075 cfm, 107 °F water side, 66.5 gpm, Design FF, 1 tube plugged

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,640.87	19,464.32
Inlet Temperature (°F)	148.00	107.00
Outlet Temperature (°F)	131.79	128.77
Inlet Specific Humidity		
Outlet Specific Humidity		

Tube-Side hi (BTU/hr·ft^{2}·°F)	0.00
j Factor	0.0000
Air-Side ho (BTU/hr·ft^{2}·°F)	0.00
Tube Wall Resistance (hr·ft^{2}·°F/BTU)	0.00024732
Overall Fouling (hr·ft^{2}·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^{2}·°F)	
Effective Area (ft^{2})	2,726.55
LMTD	0.00
Total Heat Transferred (BTU/hr)	424,209
Surface Effectiveness (Eta)	0.0000
Sensible Heat Transferred (BTU/hr)	424,209
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,640.87	19,464.32
Inlet Temperature (°F)	148.00	119.19
Outlet Temperature (°F)	143.95	130.10
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	145.97	124.6468
Skin Temperature (°F)	136.04	132.4445
Velocity ***	5,736.24	0.7619
Reynold's Number	2,084	5,758
Prandtl Number	0.7253	3.4667
Bulk Visc (lbm/ft·hr)	0.0491	1.2896
Skin Visc (lbm/ft·hr)	0.0000	1.2027
Density (lbm/ft^{3})	0.0620	61.6382
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0163	0.3716
Relative Humidity In (%)	12.76	
Relative Humidity Out (%)	14.12	

Tube-Side hi (BTU/hr·ft^{2}·°F)	304.04
j Factor	0.0106
Air-Side ho (BTU/hr·ft^{2}·°F)	18.03
Tube Wall Resistance (hr·ft^{2}·°F/BTU)	0.00024732
Overall Fouling (hr·ft^{2}·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^{2}·°F)	7.48
Effective Area (ft^{2})	681.64
LMTD	20.80
Total Heat Transferred (BTU/hr)	106,080
Surface Effectiveness (Eta)	0.8907
Sensible Heat Transferred (BTU/hr)	106,080
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^{2}), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 - 148 °F air side, 27,075 cfm, 107 °F water side, 66.5 gpm, Design FF, 1 tube plugged

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,640.87	19,464.32
Inlet Temperature (°F)	143.95	117.48
Outlet Temperature (°F)	140.25	127.45
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	142.10	122.4658
Skin Temperature (°F)	133.01	129.7309
Velocity ***	5,736.24	0.7615
Reynold's Number	2,094	5,643
Prandtl Number	0.7257	3.5438
Bulk Visc (lbm/ft·hr)	0.0489	1.3158
Skin Visc (lbm/ft·hr)	0.0000	1.2318
Density (lbm/ft³)	0.0624	61.6730
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3708
Relative Humidity In (%)	14.12	
Relative Humidity Out (%)	15.52	

Tube-Side hi (BTU/hr·ft²·°F)	297.87
j Factor	0.0105
Air-Side ho (BTU/hr·ft²·°F)	18.00
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	7.42
Effective Area (ft²)	681.64
LMTD	19.16
Total Heat Transferred (BTU/hr)	96,874
Surface Effectiveness (Eta)	0.8909
Sensible Heat Transferred (BTU/hr)	96,874
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,640.87	19,464.32
Inlet Temperature (°F)	140.25	106.96
Outlet Temperature (°F)	135.70	119.19
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	137.98	113.0737
Skin Temperature (°F)	126.82	122.7968
Velocity ***	5,736.24	0.7598
Reynold's Number	2,105	5,159
Prandtl Number	0.7260	3.9104
Bulk Visc (lbm/ft·hr)	0.0486	1.4393
Skin Visc (lbm/ft·hr)	0.0000	1.3117
Density (lbm/ft³)	0.0629	61.8159
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3676
Relative Humidity In (%)	15.52	
Relative Humidity Out (%)	17.46	

Tube-Side hi (BTU/hr·ft²·°F)	272.81
j Factor	0.0105
Air-Side ho (BTU/hr·ft²·°F)	17.96
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	7.17
Effective Area (ft²)	681.64
LMTD	24.34
Total Heat Transferred (BTU/hr)	118,921
Surface Effectiveness (Eta)	0.8911
Sensible Heat Transferred (BTU/hr)	118,921
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 - 148 °F air side, 27,075 cfm, 107 °F water side, 66.5 gpm, Design FF, 1 tube plugged

Extrapolation Calculation for Row 4(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	104,640.87	19,464.32
Inlet Temperature (°F)	135.70	106.96
Outlet Temperature (°F)	131.79	117.48
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	133.75	112.2195
Skin Temperature (°F)	124.13	120.6718
Velocity ***	5,736.24	0.7596
Reynold's Number	2,117	5,115
Prandtl Number	0.7264	3.9468
Bulk Visc (lbm/ft·hr)	0.0484	1.4515
Skin Visc (lbm/ft·hr)	0.0000	1.3380
Density (lbm/ft^3)	0.0633	61.8283
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3673
Relative Humidity In (%)	17.46	
Relative Humidity Out (%)	19.35	

Tube-Side hi (BTU/hr·ft^2·°F)	269.98
j Factor	0.0105
Air-Side ho (BTU/hr·ft^2·°F)	17.92
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	7.13
Effective Area (ft^2)	681.64
LMTD	21.05
Total Heat Transferred (BTU/hr)	102,335
Surface Effectiveness (Eta)	0.8913
Sensible Heat Transferred (BTU/hr)	102,335
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

04-26-2012 07:05:11 **PROTO-HX 4.01 by Proto-Power Corporation (SN#PHX-1002)**

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Data Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 - 148 °F air side, 27,075 cfm, 107 °F water side, 66.5 gpm, Design FF, 1 tube plugged

Air Coil Heat Exchanger Input Parameters

	Air-Side		Tube-Side	
Flow	32,483.00	acfm	82.00	gpm
Mass Flow	0.00	lbm/hr	0.00	lbm/hr
Dry Bulb (Inlet Temperature)	0.00	°F	105.00	°F
Inlet Wet Bulb Temperature	0.00	°F		
Inlet Relative Humidity	0.00	%		
Dry Bulb (Outlet Temperature)	0.00	°F	0.00	°F
Outlet Wet Bulb Temperature	0.00	°F		
Outlet Relative Humidity	0.00	%		

Tube Fluid Name	Fresh Water
Tube-Side Fouling	0.001500
Air-Side Fouling	0.000000
Design Q (BTU/hr)	
Atmospheric Pressure (psia)	14.315
Design Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Coil Flow Direction	Counter Flow
Fin Type	Circular Fins
Configuration (for Air-Side h)	LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	19.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 - 148 °F air side, 27,075 cfm, 107 °F water side, 66.5 gpm, Design FF, 1 tube plugged

Calculation Specifications

Constant Inlet Temperature Method Was Used

Extrapolation Was to User Specified Conditions

Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure (psia)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	27.30
Air Flow (acfm)	27,561.00
Tube Inlet Temp (°F)	107.00
Air Inlet Temp (°F)	131.79
Inlet Relative Humidity (%)	19.35
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure (psia)	14.315

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 - 148 °F air side, 27,075 cfm, 107 °F water side, 66.5 gpm, Design FF, 1 tube plugged

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,640.61	13,555.51
Inlet Temperature (°F)	131.79	107.00
Outlet Temperature (°F)	121.35	127.22
Inlet Specific Humidity		
Outlet Specific Humidity		

Tube-Side hi (BTU/hr·ft²·°F)	0.00
j Factor	0.0000
Air-Side ho (BTU/hr·ft²·°F)	0.00
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	5,453.10
LMTD	0.00
Total Heat Transferred (BTU/hr)	273,285
Surface Effectiveness (Eta)	0.0000
Sensible Heat Transferred (BTU/hr)	273,285
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,640.61	13,555.51
Inlet Temperature (°F)	131.79	124.51
Outlet Temperature (°F)	130.96	127.72
Inlet Specific Humidity	0.020255	
Outlet Specific Humidity	0.020255	
Average Temp (°F)	131.37	126.1164
Skin Temperature (°F)	129.48	128.7309
Velocity ***	5,736.23	0.5308
Reynold's Number	1,592	4,064
Prandtl Number	0.7266	3.4163
Bulk Visc (lbm/ft·hr)	0.0482	1.2724
Skin Visc (lbm/ft·hr)	0.0000	1.2428
Density (lbm/ft³)	0.0634	61.6145
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3720
Relative Humidity In (%)	19.35	
Relative Humidity Out (%)	19.78	

Tube-Side hi (BTU/hr·ft²·°F)	187.93
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.76
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	6.29
Effective Area (ft²)	681.64
LMTD	5.08
Total Heat Transferred (BTU/hr)	21,784
Surface Effectiveness (Eta)	0.8818
Sensible Heat Transferred (BTU/hr)	21,784
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 - 148 °F air side, 27,075 cfm, 107 °F water side, 66.5 gpm, Design FF, 1 tube plugged

Extrapolation Calculation for Row 2(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	104,640.61	13,555.51
Inlet Temperature (°F)	130.96	123.37
Outlet Temperature (°F)	130.09	126.71
Inlet Specific Humidity	0.020255	
Outlet Specific Humidity	0.020255	
Average Temp (°F)	130.53	125.0365
Skin Temperature (°F)	128.56	127.7817
Velocity ***	5,736.23	0.5307
Reynold's Number	1,594	4,024
Prandtl Number	0.7266	3.4533
Bulk Visc (lbm/ft·hr)	0.0481	1.2850
Skin Visc (lbm/ft·hr)	0.0000	1.2534
Density (lbm/ft^3)	0.0635	61.6320
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3717
Relative Humidity In (%)	19.78	
Relative Humidity Out (%)	20.24	

Tube-Side hi (BTU/hr·ft^2·°F)	185.77
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.75
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	6.25
Effective Area (ft^2)	681.64
LMTD	5.31
Total Heat Transferred (BTU/hr)	22,618
Surface Effectiveness (Eta)	0.8819
Sensible Heat Transferred (BTU/hr)	22,618
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	104,640.61	13,555.51
Inlet Temperature (°F)	130.09	120.19
Outlet Temperature (°F)	128.98	124.51
Inlet Specific Humidity	0.020255	
Outlet Specific Humidity	0.020255	
Average Temp (°F)	129.54	122.3516
Skin Temperature (°F)	126.99	125.9955
Velocity ***	5,736.23	0.5303
Reynold's Number	1,596	3,926
Prandtl Number	0.7267	3.5479
Bulk Visc (lbm/ft·hr)	0.0481	1.3171
Skin Visc (lbm/ft·hr)	0.0000	1.2738
Density (lbm/ft^3)	0.0636	61.6749
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3708
Relative Humidity In (%)	20.24	
Relative Humidity Out (%)	20.85	

Tube-Side hi (BTU/hr·ft^2·°F)	180.50
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.74
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	6.16
Effective Area (ft^2)	681.64
LMTD	6.95
Total Heat Transferred (BTU/hr)	29,200
Surface Effectiveness (Eta)	0.8819
Sensible Heat Transferred (BTU/hr)	29,200
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,640.61	13,555.51
Inlet Temperature (°F)	128.98	119.07
Outlet Temperature (°F)	127.87	123.37
Inlet Specific Humidity	0.020255	
Outlet Specific Humidity	0.020255	
Average Temp (°F)	128.42	121.2174
Skin Temperature (°F)	125.89	124.8943
Velocity ***	5,736.23	0.5302
Reynold's Number	1,599	3,885
Prandtl Number	0.7268	3.5892
Bulk Visc (lbm/ft·hr)	0.0480	1.3311
Skin Visc (lbm/ft·hr)	0.0000	1.2866
Density (lbm/ft^3)	0.0637	61.6927
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3704
Relative Humidity In (%)	20.85	
Relative Humidity Out (%)	21.48	

Tube-Side hi (BTU/hr·ft^2·°F)	178.19
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.73
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	6.12
Effective Area (ft^2)	681.64
LMTD	6.98
Total Heat Transferred (BTU/hr)	29,100
Surface Effectiveness (Eta)	0.8820
Sensible Heat Transferred (BTU/hr)	29,100
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,640.61	13,555.51
Inlet Temperature (°F)	127.87	114.48
Outlet Temperature (°F)	126.39	120.19
Inlet Specific Humidity	0.020255	
Outlet Specific Humidity	0.020255	
Average Temp (°F)	127.13	117.3359
Skin Temperature (°F)	123.76	122.4389
Velocity ***	5,736.23	0.5297
Reynold's Number	1,601	3,745
Prandtl Number	0.7269	3.7367
Bulk Visc (lbm/ft·hr)	0.0479	1.3810
Skin Visc (lbm/ft·hr)	0.0000	1.3161
Density (lbm/ft^3)	0.0639	61.7525
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3691
Relative Humidity In (%)	21.48	
Relative Humidity Out (%)	22.36	

Tube-Side hi (BTU/hr·ft^2·°F)	170.55
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.72
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	5.98
Effective Area (ft^2)	681.64
LMTD	9.49
Total Heat Transferred (BTU/hr)	38,704
Surface Effectiveness (Eta)	0.8820
Sensible Heat Transferred (BTU/hr)	38,704
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 - 148 °F air side, 27,075 cfm, 107 °F water side, 66.5 gpm, Design FF, 1 tube plugged

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,640.61	13,555.51
Inlet Temperature (°F)	126.39	113.66
Outlet Temperature (°F)	124.99	119.07
Inlet Specific Humidity	0.020255	
Outlet Specific Humidity	0.020255	
Average Temp (°F)	125.69	116.3626
Skin Temperature (°F)	122.50	121.2497
Velocity ***	5,736.23	0.5295
Reynold's Number	1,604	3,710
Prandtl Number	0.7270	3.7752
Bulk Visc (lbm/ft·hr)	0.0478	1.3939
Skin Visc (lbm/ft·hr)	0.0000	1.3307
Density (lbm/ft^3)	0.0640	61.7672
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3688
Relative Humidity In (%)	22.36	
Relative Humidity Out (%)	23.23	

Tube-Side hi (BTU/hr·ft^2·°F)	168.50
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.70
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	5.94
Effective Area (ft^2)	681.64
LMTD	9.04
Total Heat Transferred (BTU/hr)	36,639
Surface Effectiveness (Eta)	0.8821
Sensible Heat Transferred (BTU/hr)	36,639
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,640.61	13,555.51
Inlet Temperature (°F)	124.99	107.04
Outlet Temperature (°F)	123.06	114.48
Inlet Specific Humidity	0.020255	
Outlet Specific Humidity	0.020255	
Average Temp (°F)	124.03	110.7576
Skin Temperature (°F)	119.65	117.9344
Velocity ***	5,736.23	0.5288
Reynold's Number	1,608	3,511
Prandtl Number	0.7271	4.0103
Bulk Visc (lbm/ft·hr)	0.0477	1.4728
Skin Visc (lbm/ft·hr)	0.0000	1.3731
Density (lbm/ft^3)	0.0642	61.8492
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3668
Relative Humidity In (%)	23.23	
Relative Humidity Out (%)	24.48	

Tube-Side hi (BTU/hr·ft^2·°F)	157.40
j Factor	0.0115
Air-Side ho (BTU/hr·ft^2·°F)	19.68
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	5.73
Effective Area (ft^2)	681.64
LMTD	12.89
Total Heat Transferred (BTU/hr)	50,363
Surface Effectiveness (Eta)	0.8822
Sensible Heat Transferred (BTU/hr)	50,363
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	104,640.61	13,555.51
Inlet Temperature (°F)	123.06	107.03
Outlet Temperature (°F)	121.35	113.66
Inlet Specific Humidity	0.020255	
Outlet Specific Humidity	0.020255	
Average Temp (°F)	122.21	110.3426
Skin Temperature (°F)	118.30	116.7770
Velocity ***	5,736.23	0.5288
Reynold's Number	1,612	3,497
Prandtl Number	0.7273	4.0287
Bulk Visc (lbm/ft·hr)	0.0476	1.4789
Skin Visc (lbm/ft·hr)	0.0000	1.3884
Density (lbm/ft³)	0.0644	61.8552
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3667
Relative Humidity In (%)	24.48	
Relative Humidity Out (%)	25.67	

Tube-Side hi (BTU/hr·ft²·°F)	156.39
j Factor	0.0115
Air-Side ho (BTU/hr·ft²·°F)	19.67
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	5.71
Effective Area (ft²)	681.64
LMTD	11.53
Total Heat Transferred (BTU/hr)	44,875
Surface Effectiveness (Eta)	0.8823
Sensible Heat Transferred (BTU/hr)	44,875
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Back						
Formulas from Section 6.8 for iteration process to determine inlet airflow for extrapolation conditions						
Total P:	P =			14.315	psia	
Dry Bulb T OUT:	T1 =			121.35	F	
Specific Hum.:	W =			0.02026		
H2O Vap. P:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =			0.45158	psia	
			Rv =	85.778	(ft-lbf)/(lbm-R)	
			Ra =	53.352	(ft-lbf)/(lbm-R)	
Dry Air P:	Pa = P - Pv =			13.86342	psia	
Dry Air rho OUT:	rho.out = (144/Ra)*(Pa/(459.67+T1)) =			0.064401	lbm/ft^3	
Dry Air rho IN:	rho.in = (144/Ra)*(Pa/(459.67+T2)) =			0.063264	lbm/ft^3	
Dry Bulb T IN:	T2 =			131.79	F	
Outlet Air Flow:	V =			27075	cfm	
cfm.in	cfm.in = V*(rho.out/rho.in) =			27561.49	acfm	
Front						
Formulas from Section 6.8 for iteration process to determine inlet airflow for extrapolation conditions						
Total P:	P =			14.315	psia	
Dry Bulb T OUT:	T1 =			131.79	F	
Specific Hum.:	W =			0.02026		
H2O Vap. P:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =			0.45158	psia	
			Rv =	85.778	(ft-lbf)/(lbm-R)	
			Ra =	53.352	(ft-lbf)/(lbm-R)	
Dry Air P:	Pa = P - Pv =			13.86342	psia	
Dry Air rho OUT:	rho.out = (144/Ra)*(Pa/(459.67+T1)) =			0.063264	lbm/ft^3	
Dry Air rho IN:	rho.in = (144/Ra)*(Pa/(459.67+T2)) =			0.061576	lbm/ft^3	
Dry Bulb T IN:	T2 =			148	F	
Outlet Air Flow:	V =			27561	cfm	
cfm.in	cfm.in = V*(rho.out/rho.in) =			28316.87	acfm	

CC-AA-309-1001
Revision 1

ATTACHMENT 2
Design Analysis Minor Revision Cover Sheet
Page 1 of ~~1~~ 3

* Plus Attachments A Page A1-A12 Attachment B Pages B1-B12

Last Page No. 3 *

Analysis No. 97-198 **Revision** A02

EC/ECR No. 356225 **Revision** 0

Title: VY Cooler Thermal Performance Model - 1(2)VY04A

Station(s) LaSalle

Unit No.: 01/02

Safety Class SR

System Code VY

Is this Design Analysis Safeguards? Yes ☐ No ☒

Does this Design Analysis Contain Unverified Assumptions? Yes ☐ No ☒

ATI/AR#

Description of Change

This minor revision reduces the amount of air flow required into the 1(2)VY04A coolers by 5%, and determines a new maximum fouling factor at this reduced air flow.

Disposition of Changes (include additional pages as required)

See attached sheets. The change is acceptable.

Preparer	Terry Martin		7/6/05
	Print Name	Sign Name	Date
Reviewer	DAN SCHMIT	DJSchmit	7/6/05
	Print Name	Sign Name	Date

Method of Review ☑ Detailed Review ☐ Alternate Calculations ☐ Testing

Review Notes:

Approver	W. Hilten		7-6-05
	Print Name	Sign Name	Date

(For External Analyses Only)

Exelon Reviewer			
	Print Name	Sign Name	Date
Approver			
	Print Name	Sign Name	Date

Purpose:

The purpose of this minor revision is to revise the thermal model of the 1(2)VY04A coolers for a 5% reduction in airflow. This assessment will evaluate the adequacy of these heat exchangers with a maximum allowable inlet service water temperature of 104°F, using the design fouling factor of 0.02228812, and 5% tube plugging. Another case will be run to find the maximum fouling factor with the 5% reduction in air flow and 5% of the tubes plugged.

Inputs:

The design inputs consist of Reference 1 listed below.

Assumptions:

The assumptions indicated in section 5.0 of Reference 1 are still valid.

References:

1. Calculation No. 97-198, Rev. A, "Thermal Model of COMED / LaSalle Station Unit 1 and 2 LPCS Pump Room Coolers."

Identification of Computer Programs:

Proto Hx version 4.01 is used for this minor revision. The same software was used for the other revisions in this calculation.

Method of Analysis and Acceptance Criteria:

The existing heat exchanger model will be revised by changing the input of the air inlet flow rate, but the air flow rate is measured on the discharge of the cooler. Therefore, the 5% reduction is calculated on the exit of the cooler by manipulation of the inlet air flow rate. This reduction in flow along with the 5% plugged tubes, design fouling factor, and 104°F incoming cooling water was used to determine the thermal margin of the coolers and the maximum fouling factor. The acceptance criteria will be for the calculated heat transfer to exceed the LaSalle design heat load of 633,288 BTU/hr for 1(2)VY04A coolers (See Reference 1, Table 1). The original benchmark model developed for these heat exchangers demonstrated a correlation to vendor performance specification within an assumed 5% margin.

Analysis:

All input parameters except for air flow rate have remained the same and will not change for this model. Proto HX requires the inlet air flow rate, but our flow device is located on the exit of the heat exchanger. Each of the coolers actually has two coolers in one (a front and back cooler). Therefore this revision will drop the front cooler air flow by 5% and the back cooler will take the exit flow rate of the front decreased from cooling of the air as its inlet flow. This translates to more than a 5% reduction in overall exit flow and therefore is conservative. The current analyzed exit flow rate is taken from the 4th row of the front cooler (see Reference 1 Rev A00 Attachment B, page B6), which is 108,332.51 lbm/hr. Dividing this mass flow rate by the density (which is also on that same page) and converting to minutes gives an exit flow rate of 28,479 CFM. Reducing this number by

5% results in an exit flow rate of 27,058 CFM. Manipulation of the inlet flow rate was used until the exit flow rate is 27,058 CFM. Using this value for the inlet to the back cooler results in an exit flow rate of 26,520 CFM. Therefore the total reduction in air is 6.9%, which is more than 5%.

When the Service Water inlet temperature is 104°F for the limiting flow rate of 39.20 gpm, a design fouling factor of 0.02228812 hr*ft^2*°F/BTU, and a 5% tube plugging allowance, the new total heat transfer is 450,396 BTU/hr for the front cooler and 290,765 BTU/hr for the back cooler for a total of 741,161 BTU/hr. The thermal margin is calculated as Qcalculated – Qrequired, which is 741,161 – 633,288 BTU/hr = 107,873 or 17.0 % gross Thermal Margin. Allowing for 5% model uncertainty, the net margin is 741,161(0.95) – 633,288 = 70,815 or 11.2% Thermal Margin.

The maximum fouling factor with the same assumptions as above and a 5% model uncertainty is 0.07479374 hr*ft^2*°F/BTU.

Results / Conclusion:

The 1(2)VY04A coolers were found to have adequate thermal margin for a maximum lake temperature of 104°F when operated at design fouling conditions (0.02228812 hr*ft^2*°F/BTU), a 5% tube plugging allowance, and a 5% reduction in air flow rate. The maximum fouling factor is 0.07479374 hr*ft^2*°F/BTU. A reduced airflow rate of 27,075 ACFM (95% of 28,500) may therefore be used as acceptance criteria for airside flow rate testing (e.g. LTS-200-19).

Attachments:

Attachment "A" – Proto-Hx Calc. Report for 1(2)VY04A
    (CSCS=104°F @ design fouling, 5% tube plugged, 5% reduction in flow)
Attachment "B" – Proto-Hx Calc. Report for 1(2)VY04A
    (CSCS=104°F Max FF, 5% tube plugged, 5% reduction in flow)

8/31/05

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07-05-2005 08:51:34 **PROTO-HX 4.01 by Proto-Power Corporation (SN#PHX-0000)**

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Data Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04, 5% Plug, Design FF, 5% reduction in air flow 6/29/05

Air Coil Heat Exchanger Input Parameters

	Air-Side		Tube-Side	
Flow	33,546.00	acfm	118.00	gpm
Mass Flow	0.00	lbm/hr	0.00	lbm/hr
Dry Bulb (Inlet Temperature)	150.00	°F	105.00	°F
Inlet Wet Bulb Temperature	92.00	°F		
Inlet Relative Humidity	0.00	%		
Dry Bulb (Outlet Temperature)	0.00	°F	0.00	°F
Outlet Wet Bulb Temperature	0.00	°F		
Outlet Relative Humidity	0.00	%		

Tube Fluid Name	Fresh Water
Tube-Side Fouling	0.001500
Air-Side Fouling	0.000000
Design Q (BTU/hr)	
Atmospheric Pressure (psia)	14.315
Design Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Coil Flow Direction	Counter Flow
Fin Type	Circular Fins
Configuration (for Air-Side h)	LaSalle VY Cooler 04A
	j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	19.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Conductivity (BTU/hr·ft·°F)	225.00

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Attachment A
Page A1 of A12

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Calculation Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04, 5% Plug, Design FF, 5% reduction in air flow 6/29/05

Calculation Specifications

Constant Inlet Temperature Method Was Used

Extrapolation Was to User Specified Conditions

Design Fouling Factors Were Used

Test Data

Data Date

Air Flow (acfm)

Air Dry Bulb Temp In (°F)

Air Dry Bulb Temp Out (°F)

Relative Humidity In (%)

Relative Humidity Out (%)

Wet Bulb Temp In (°F)

Wet Bulb Temp Out (°F)

Atmospheric Pressure (psia)

Tube Flow (gpm)

Tube Temp In (°F)

Tube Temp Out (°F)

Condensate Temperature (°F)

Extrapolation Data

Tube Flow (gpm)	39.20
Air Flow (acfm)	27,854.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	148.00
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure (psia)	14.315

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Attachment A
Page A2

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04, 5% Plug, Design FF, 5% reduction in air flow 6/29/05

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,929.93	19,477.06
Inlet Temperature (°F)	148.00	104.00
Outlet Temperature (°F)	130.51	127.16
Inlet Specific Humidity		
Outlet Specific Humidity		

Tube-Side hi (BTU/hr·ft²·°F)	0.00
j Factor	0.0000
Air-Side ho (BTU/hr·ft²·°F)	0.00
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	2,726.55
LMTD	0.00
Total Heat Transferred (BTU/hr)	450,396
Surface Effectiveness (Eta)	0.0000
Sensible Heat Transferred (BTU/hr)	450,396
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,929.93	19,477.06
Inlet Temperature (°F)	148.00	116.91
Outlet Temperature (°F)	143.59	128.58
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	145.80	122.7422
Skin Temperature (°F)	135.06	131.2162
Velocity ***	5.642.45	0.7621
Reynold's Number	2.050	5,661
Prandtl Number	0.7253	3.5339
Bulk Visc (lbm/ft·hr)	0.0491	1.3124
Skin Visc (lbm/ft·hr)	0.0000	1.2157
Density (lbm/ft³)	0.0620	61.6687
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0163	0.3709
Relative Humidity In (%)	12.76	
Relative Humidity Out (%)	14.25	

Tube-Side hi (BTU/hr·ft²·°F)	299.33
j Factor	0.0106
Air-Side ho (BTU/hr·ft²·°F)	17.84
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	7.41
Effective Area (ft²)	681.64
LMTD	22.49
Total Heat Transferred (BTU/hr)	113,542
Surface Effectiveness (Eta)	0.8917
Sensible Heat Transferred (BTU/hr)	113,542
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04, 5% Plug, Design FF, 5% reduction in air flow 6/29/05

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,929.93	19,477.06
Inlet Temperature (°F)	143.59	115.13
Outlet Temperature (°F)	139.58	125.75
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	141.59	120.4390
Skin Temperature (°F)	131.81	128.3139
Velocity ***	5,642.45	0.7616
Reynold's Number	2,061	5,541
Prandtl Number	0.7257	3.6180
Bulk Visc (lbm/ft·hr)	0.0488	1.3409
Skin Visc (lbm/ft·hr)	0.0000	1.2474
Density (lbm/ft^3)	0.0625	61.7048
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3702
Relative Humidity In (%)	14.25	
Relative Humidity Out (%)	15.79	

Tube-Side hi (BTU/hr·ft^2·°F)	292.77
j Factor	0.0106
Air-Side ho (BTU/hr·ft^2·°F)	17.80
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	7.34
Effective Area (ft^2)	681.64
LMTD	20.64
Total Heat Transferred (BTU/hr)	103,257
Surface Effectiveness (Eta)	0.8919
Sensible Heat Transferred (BTU/hr)	103,257
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,929.93	19,477.06
Inlet Temperature (°F)	139.58	103.98
Outlet Temperature (°F)	134.70	116.91
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	137.14	110.4436
Skin Temperature (°F)	125.23	120.9806
Velocity ***	5,642.45	0.7598
Reynold's Number	2,073	5,029
Prandtl Number	0.7261	4.0242
Bulk Visc (lbm/ft·hr)	0.0486	1.4774
Skin Visc (lbm/ft·hr)	0.0000	1.3341
Density (lbm/ft^3)	0.0630	61.8537
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3667
Relative Humidity In (%)	15.79	
Relative Humidity Out (%)	17.93	

Tube-Side hi (BTU/hr·ft^2·°F)	265.99
j Factor	0.0106
Air-Side ho (BTU/hr·ft^2·°F)	17.76
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	7.07
Effective Area (ft^2)	681.64
LMTD	26.10
Total Heat Transferred (BTU/hr)	125,736
Surface Effectiveness (Eta)	0.8921
Sensible Heat Transferred (BTU/hr)	125,736
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec): Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	102,929.93	19,477.06
Inlet Temperature (°F)	134.70	104.04
Outlet Temperature (°F)	130.51	115.13
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	132.60	109.5872
Skin Temperature (°F)	122.37	118.7232
Velocity ***	5.642.45	0.7596
Reynold's Number	2.085	4,986
Prandtl Number	0.7265	4.0624
Bulk Visc (lbm/ft·hr)	0.0483	1.4902
Skin Visc (lbm/ft·hr)	0.0000	1.3628
Density (lbm/ft^3)	0.0634	61.8658
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3664
Relative Humidity In (%)	17.93	
Relative Humidity Out (%)	20.03	

Tube-Side hi (BTU/hr·ft^2·°F)	263.11
j Factor	0.0106
Air-Side ho (BTU/hr·ft^2·°F)	17.72
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	7.03
Effective Area (ft^2)	681.64
LMTD	22.51
Total Heat Transferred (BTU/hr)	107,861
Surface Effectiveness (Eta)	0.8923
Sensible Heat Transferred (BTU/hr)	107,861
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Data Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04, 5% Plug, Design FF, 5% reduction in air flow 6/29/05

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Flow	32,483.00 acfm	82.00 gpm
Mass Flow	0.00 lbm/hr	0.00 lbm/hr
Dry Bulb (Inlet Temperature)	0.00 °F	105.00 °F
Inlet Wet Bulb Temperature	0.00 °F	
Inlet Relative Humidity	0.00 %	
Dry Bulb (Outlet Temperature)	0.00 °F	0.00 °F
Outlet Wet Bulb Temperature	0.00 °F	
Outlet Relative Humidity	0.00 %	

Tube Fluid Name	Fresh Water
Tube-Side Fouling	0.001500
Air-Side Fouling	0.000000
Design Q (BTU/hr)	
Atmospheric Pressure (psia)	14.315
Design Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Coil Flow Direction	Counter Flow
Fin Type	Circular Fins
Configuration (for Air-Side h)	LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	19.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04, 5% Plug, Design FF, 5% reduction in air flow 6/29/05

Calculation Specifications

Constant Inlet Temperature Method Was Used

Extrapolation Was to User Specified Conditions

Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure (psia)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	27.30
Air Flow (acfm)	27,058.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	130.51
Inlet Relative Humidity (%)	20.03
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure (psia)	14.315

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*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04, 5% Plug, Design FF, 5% reduction in air flow 6/29/05

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,952.03	13,564.38
Inlet Temperature (°F)	130.51	104.00
Outlet Temperature (°F)	119.22	125.43
Inlet Specific Humidity		
Outlet Specific Humidity		

Tube-Side hi (BTU/hr·ft^2·°F)	0.00
j Factor	0.0000
Air-Side ho (BTU/hr·ft^2·°F)	0.00
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	
Effective Area (ft^2)	5,453.10
LMTD	0.00
Total Heat Transferred (BTU/hr)	290,765
Surface Effectiveness (Eta)	0.0000
Sensible Heat Transferred (BTU/hr)	290,765
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,952.03	13,564.38
Inlet Temperature (°F)	130.51	122.48
Outlet Temperature (°F)	129.59	125.99
Inlet Specific Humidity	0.020265	
Outlet Specific Humidity	0.020265	
Average Temp (°F)	130.05	124.2348
Skin Temperature (°F)	127.96	127.1431
Velocity ***	5.643.66	0.5309
Reynold's Number	1.569	3,997
Prandtl Number	0.7267	3.4811
Bulk Visc (lbm/ft·hr)	0.0481	1.2944
Skin Visc (lbm/ft·hr)	0.0000	1.2606
Density (lbm/ft^3)	0.0635	61.6449
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3714
Relative Humidity In (%)	20.03	
Relative Humidity Out (%)	20.53	

Tube-Side hi (BTU/hr·ft^2·°F)	184.35
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.54
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	6.21
Effective Area (ft^2)	681.64
LMTD	5.62
Total Heat Transferred (BTU/hr)	23,790
Surface Effectiveness (Eta)	0.8830
Sensible Heat Transferred (BTU/hr)	23,790
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04, 5% Plug, Design FF, 5% reduction in air flow 6/29/05

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	102,952.03	13,564.38	Tube-Side hi (BTU/hr·ft^2·°F)	182.00
Inlet Temperature (°F)	129.59	121.25	j Factor	0.0116
Outlet Temperature (°F)	128.63	124.88	Air-Side ho (BTU/hr·ft^2·°F)	19.53
Inlet Specific Humidity	0.020265		Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Outlet Specific Humidity	0.020265		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	129.11	123.0662		
Skin Temperature (°F)	126.95	126.1082	U Overall (BTU/hr·ft^2·°F)	6.17
Velocity ***	5,643.66	0.5308	Effective Area (ft^2)	681.64
Reynold's Number	1,571	3,955	LMTD	5.85
Prandtl Number	0.7267	3.5223	Total Heat Transferred (BTU/hr)	24,578
Bulk Visc (lbm/ft·hr)	0.0481	1.3085		
Skin Visc (lbm/ft·hr)	0.0000	1.2725	Surface Effectiveness (Eta)	0.8830
Density (lbm/ft^3)	0.0636	61.6635	Sensible Heat Transferred (BTU/hr)	24,578
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0159	0.3710	Heat to Condensate (BTU/hr)	
Relative Humidity In (%)	20.53			
Relative Humidity Out (%)	21.06			

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	102,952.03	13,564.38	Tube-Side hi (BTU/hr·ft^2·°F)	176.27
Inlet Temperature (°F)	128.63	117.83	j Factor	0.0116
Outlet Temperature (°F)	127.41	122.48	Air-Side ho (BTU/hr·ft^2·°F)	19.52
Inlet Specific Humidity	0.020265		Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Outlet Specific Humidity	0.020265		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	128.02	120.1542		
Skin Temperature (°F)	125.25	124.1762	U Overall (BTU/hr·ft^2·°F)	6.07
Velocity ***	5,643.66	0.5304	Effective Area (ft^2)	681.64
Reynold's Number	1,574	3,849	LMTD	7.62
Prandtl Number	0.7268	3.6287	Total Heat Transferred (BTU/hr)	31,504
Bulk Visc (lbm/ft·hr)	0.0480	1.3445		
Skin Visc (lbm/ft·hr)	0.0000	1.2951	Surface Effectiveness (Eta)	0.8831
Density (lbm/ft^3)	0.0637	61.7093	Sensible Heat Transferred (BTU/hr)	31,504
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0159	0.3701	Heat to Condensate (BTU/hr)	
Relative Humidity In (%)	21.06			
Relative Humidity Out (%)	21.76			

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*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,952.03	13,564.38
Inlet Temperature (°F)	127.41	116.64
Outlet Temperature (°F)	126.20	121.25
Inlet Specific Humidity	0.020265	
Outlet Specific Humidity	0.020265	
Average Temp (°F)	126.80	118.9467
Skin Temperature (°F)	124.06	122.9902
Velocity ***	5,643.66	0.5302
Reynold's Number	1,576	3,805
Prandtl Number	0.7269	3.6743
Bulk Visc (lbm/ft·hr)	0.0479	1.3599
Skin Visc (lbm/ft·hr)	0.0000	1.3094
Density (lbm/ft³)	0.0639	61.7279
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3697
Relative Humidity In (%)	21.76	
Relative Humidity Out (%)	22.49	

Tube-Side hi (BTU/hr·ft²·°F)	173.80
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.50
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	6.02
Effective Area (ft²)	681.64
LMTD	7.61
Total Heat Transferred (BTU/hr)	31,242
Surface Effectiveness (Eta)	0.8831
Sensible Heat Transferred (BTU/hr)	31,242
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,952.03	13,564.38
Inlet Temperature (°F)	126.20	111.75
Outlet Temperature (°F)	124.60	117.83
Inlet Specific Humidity	0.020265	
Outlet Specific Humidity	0.020265	
Average Temp (°F)	125.40	114.7885
Skin Temperature (°F)	121.78	120.3756
Velocity ***	5,643.66	0.5297
Reynold's Number	1,579	3,656
Prandtl Number	0.7270	3.8389
Bulk Visc (lbm/ft·hr)	0.0478	1.4154
Skin Visc (lbm/ft·hr)	0.0000	1.3417
Density (lbm/ft³)	0.0641	61.7907
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3682
Relative Humidity In (%)	22.49	
Relative Humidity Out (%)	23.49	

Tube-Side hi (BTU/hr·ft²·°F)	165.58
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.49
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	5.87
Effective Area (ft²)	681.64
LMTD	10.29
Total Heat Transferred (BTU/hr)	41,187
Surface Effectiveness (Eta)	0.8832
Sensible Heat Transferred (BTU/hr)	41,187
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04, 5% Plug, Design FF, 5% reduction in air flow 6/29/05

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,952.03	13,564.38
Inlet Temperature (°F)	124.60	110.91
Outlet Temperature (°F)	123.09	116.64
Inlet Specific Humidity	0.020265	
Outlet Specific Humidity	0.020265	
Average Temp (°F)	123.84	113.7752
Skin Temperature (°F)	120.43	119.1091
Velocity ***	5.643.66	0.5296
Reynold's Number	1.582	3,620
Prandtl Number	0.7271	3.8809
Bulk Visc (lbm/ft·hr)	0.0477	1.4294
Skin Visc (lbm/ft·hr)	0.0000	1.3578
Density (lbm/ft^3)	0.0642	61.8056
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3679
Relative Humidity In (%)	23.49	
Relative Humidity Out (%)	24.48	

Tube-Side hi (BTU/hr·ft^2·°F)	163.43
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.47
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	5.83
Effective Area (ft^2)	681.64
LMTD	9.77
Total Heat Transferred (BTU/hr)	38,830
Surface Effectiveness (Eta)	0.8833
Sensible Heat Transferred (BTU/hr)	38,830
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,952.03	13,564.38
Inlet Temperature (°F)	123.09	103.96
Outlet Temperature (°F)	121.04	111.75
Inlet Specific Humidity	0.020265	
Outlet Specific Humidity	0.020265	
Average Temp (°F)	122.06	107.8562
Skin Temperature (°F)	117.44	115.6463
Velocity ***	5.643.66	0.5288
Reynold's Number	1.586	3,412
Prandtl Number	0.7273	4.1416
Bulk Visc (lbm/ft·hr)	0.0476	1.5166
Skin Visc (lbm/ft·hr)	0.0000	1.4036
Density (lbm/ft^3)	0.0644	61.8900
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3658
Relative Humidity In (%)	24.48	
Relative Humidity Out (%)	25.90	

Tube-Side hi (BTU/hr·ft^2·°F)	151.65
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.46
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	5.60
Effective Area (ft^2)	681.64
LMTD	13.83
Total Heat Transferred (BTU/hr)	52,737
Surface Effectiveness (Eta)	0.8834
Sensible Heat Transferred (BTU/hr)	52,737
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	102,952.03	13,564.38
Inlet Temperature (°F)	121.04	103.99
Outlet Temperature (°F)	119.22	110.91
Inlet Specific Humidity	0.020265	
Outlet Specific Humidity	0.020265	
Average Temp (°F)	120.13	107.4483
Skin Temperature (°F)	116.01	114.4205
Velocity ***	5.643.66	0.5288
Reynold's Number	1.590	3,398
Prandtl Number	0.7274	4.1606
Bulk Visc (lbm/ft·hr)	0.0475	1.5229
Skin Visc (lbm/ft·hr)	0.0000	1.4205
Density (lbm/ft³)	0.0647	61.8957
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3656
Relative Humidity In (%)	25.90	
Relative Humidity Out (%)	27.24	

Tube-Side hi (BTU/hr·ft²·°F)	150.63
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.44
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	5.57
Effective Area (ft²)	681.64
LMTD	12.34
Total Heat Transferred (BTU/hr)	46,896
Surface Effectiveness (Eta)	0.8835
Sensible Heat Transferred (BTU/hr)	46,896
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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Attachment A
Page A12 Final

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

06-29-2005 11:14:56 **PROTO-HX 4.01 by Proto-Power Corporation (SN#PHX-0000)**

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Data Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% Plug, 5% reduction in air, MAX FF ~~5/29/05~~ 6/29/05

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Flow	33,546.00 acfm	118.00 gpm
Mass Flow	0.00 lbm/hr	0.00 lbm/hr
Dry Bulb (Inlet Temperature)	150.00 °F	105.00 °F
Inlet Wet Bulb Temperature	92.00 °F	
Inlet Relative Humidity	0.00 %	
Dry Bulb (Outlet Temperature)	0.00 °F	0.00 °F
Outlet Wet Bulb Temperature	0.00 °F	
Outlet Relative Humidity	0.00 %	

Tube Fluid Name	Fresh Water
Tube-Side Fouling	0.005000
Air-Side Fouling	0.000500
Design Q (BTU/hr)	
Atmospheric Pressure (psia)	14.315
Design Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Coil Flow Direction	Counter Flow
Fin Type	Circular Fins
Configuration (for Air-Side h)	LaSalle VY Cooler 04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	19.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Conductivity (BTU/hr·ft·°F)	225.00

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Attachment B
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Calculation Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% Plug, 5% reduction in air, MAX FF ~~5/29/05~~ 6/29/05

Calculation Specifications

Constant Inlet Temperature Method Was Used

Extrapolation Was to User Specified Conditions

Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure (psia)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	39.20
Air Flow (acfm)	27,854.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	148.00
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure (psia)	14.315

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Attachment B
Page B2

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% Plug, 5% reduction in air, MAX FF ~~5/29/05~~ 6/29/05

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,929.93	19,477.06
Inlet Temperature (°F)	148.00	104.00
Outlet Temperature (°F)	133.38	123.34
Inlet Specific Humidity		
Outlet Specific Humidity		

Tube-Side hi (BTU/hr·ft^{2}·°F)	0.00
j Factor	0.0000
Air-Side ho (BTU/hr·ft^{2}·°F)	0.00
Tube Wall Resistance (hr·ft^{2}·°F/BTU)	0.00024732
Overall Fouling (hr·ft^{2}·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^{2}·°F)	
Effective Area (ft^{2})	2,726.55
LMTD	0.00
Total Heat Transferred (BTU/hr)	376,502
Surface Effectiveness (Eta)	0.0000
Sensible Heat Transferred (BTU/hr)	376,502
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,929.93	19,477.06
Inlet Temperature (°F)	148.00	114.54
Outlet Temperature (°F)	144.31	124.32
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	146.15	119.4304
Skin Temperature (°F)	137.27	126.6741
Velocity ***	5,642.45	0.7614
Reynold's Number	2,049	5,489
Prandtl Number	0.7253	3.6559
Bulk Visc (lbm/ft·hr)	0.0491	1.3537
Skin Visc (lbm/ft·hr)	0.0000	1.2660
Density (lbm/ft^{3})	0.0620	61.7205
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0163	0.3698
Relative Humidity In (%)	12.76	
Relative Humidity Out (%)	14.00	

Tube-Side hi (BTU/hr·ft^{2}·°F)	289.76
j Factor	0.0106
Air-Side ho (BTU/hr·ft^{2}·°F)	17.84
Tube Wall Resistance (hr·ft^{2}·°F/BTU)	0.00024732
Overall Fouling (hr·ft^{2}·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^{2}·°F)	5.29
Effective Area (ft^{2})	681.64
LMTD	26.39
Total Heat Transferred (BTU/hr)	95,075
Surface Effectiveness (Eta)	0.8917
Sensible Heat Transferred (BTU/hr)	95,075
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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Attachment B
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*** Air Mass Velocity (Lbm/hr·ft^{2}), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% Plug, 5% reduction in air, MAX FF ~~5/29/05~~ 6/29/05

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,929.93	19,477.06
Inlet Temperature (°F)	144.31	113.36
Outlet Temperature (°F)	140.90	122.36
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	142.61	117.8608
Skin Temperature (°F)	134.41	124.6414
Velocity ***	5,642.45	0.7611
Reynold's Number	2,059	5,407
Prandtl Number	0.7256	3.7162
Bulk Visc (lbm/ft·hr)	0.0489	1.3740
Skin Visc (lbm/ft·hr)	0.0000	1.2896
Density (lbm/ft³)	0.0623	61.7445
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3693
Relative Humidity In (%)	14.00	
Relative Humidity Out (%)	15.26	

Tube-Side hi (BTU/hr·ft²·°F)	285.26
j Factor	0.0106
Air-Side ho (BTU/hr·ft²·°F)	17.81
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.07479374
U Overall (BTU/hr·ft²·°F)	5.26
Effective Area (ft²)	681.64
LMTD	24.44
Total Heat Transferred (BTU/hr)	87,625
Surface Effectiveness (Eta)	0.8919
Sensible Heat Transferred (BTU/hr)	87,625
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,929.93	19,477.06
Inlet Temperature (°F)	140.90	104.01
Outlet Temperature (°F)	136.92	114.54
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	138.91	109.2760
Skin Temperature (°F)	129.32	117.9023
Velocity ***	5,642.45	0.7596
Reynold's Number	2,068	4,970
Prandtl Number	0.7259	4.0765
Bulk Visc (lbm/ft·hr)	0.0487	1.4949
Skin Visc (lbm/ft·hr)	0.0000	1.3735
Density (lbm/ft³)	0.0627	61.8702
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3663
Relative Humidity In (%)	15.26	
Relative Humidity Out (%)	16.91	

Tube-Side hi (BTU/hr·ft²·°F)	262.06
j Factor	0.0106
Air-Side ho (BTU/hr·ft²·°F)	17.77
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.07479374
U Overall (BTU/hr·ft²·°F)	5.13
Effective Area (ft²)	681.64
LMTD	29.29
Total Heat Transferred (BTU/hr)	102,471
Surface Effectiveness (Eta)	0.8920
Sensible Heat Transferred (BTU/hr)	102,471
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% Plug, 5% reduction in air, MAX FF ~~5/29/05~~ 6/29/05

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,929.93	19,477.06
Inlet Temperature (°F)	136.92	103.97
Outlet Temperature (°F)	133.38	113.36
Inlet Specific Humidity	0.020268	
Outlet Specific Humidity	0.020268	
Average Temp (°F)	135.15	108.6620
Skin Temperature (°F)	126.58	116.4098
Velocity ***	5.642.45	0.7595
Reynold's Number	2.078	4,940
Prandtl Number	0.7263	4.1044
Bulk Visc (lbm/ft·hr)	0.0484	1.5042
Skin Visc (lbm/ft·hr)	0.0000	1.3933
Density (lbm/ft^3)	0.0631	61.8788
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3661
Relative Humidity In (%)	16.91	
Relative Humidity Out (%)	18.56	

Tube-Side hi (BTU/hr·ft^2·°F)	260.04
j Factor	0.0106
Air-Side ho (BTU/hr·ft^2·°F)	17.74
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^2·°F)	5.12
Effective Area (ft^2)	681.64
LMTD	26.18
Total Heat Transferred (BTU/hr)	91,330
Surface Effectiveness (Eta)	0.8922
Sensible Heat Transferred (BTU/hr)	91,330
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Data Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% Plug, 5% reduction in air, MAX FF 6/29/05

Air Coil Heat Exchanger Input Parameters

	Air-Side		Tube-Side	
Flow	32,483.00	acfm	82.00	gpm
Mass Flow	0.00	lbm/hr	0.00	lbm/hr
Dry Bulb (Inlet Temperature)	0.00	°F	105.00	°F
Inlet Wet Bulb Temperature	0.00	°F		
Inlet Relative Humidity	0.00	%		
Dry Bulb (Outlet Temperature)	0.00	°F	0.00	°F
Outlet Wet Bulb Temperature	0.00	°F		
Outlet Relative Humidity	0.00	%		

Tube Fluid Name	Fresh Water
Tube-Side Fouling	0.005000
Air-Side Fouling	0.000500
Design Q (BTU/hr)	
Atmospheric Pressure (psia)	14.315
Design Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Coil Flow Direction	Counter Flow
Fin Type	Circular Fins
Configuration (for Air-Side h)	LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	19.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% Plug, 5% reduction in air, MAX FF 6/29/05

Calculation Specifications

Constant Inlet Temperature Method Was Used

Extrapolation Was to User Specified Conditions

Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure (psia)	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	27.30
Air Flow (acfm)	27,187.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	133.38
Inlet Relative Humidity (%)	18.56
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure (psia)	14.315

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AHB
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*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% Plug, 5% reduction in air, MAX FF 6/29/05

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,942.64	13,564.38
Inlet Temperature (°F)	133.38	104.00
Outlet Temperature (°F)	121.98	125.67
Inlet Specific Humidity		
Outlet Specific Humidity		

Tube-Side hi (BTU/hr·ft^2·°F)	0.00
j Factor	0.0000
Air-Side ho (BTU/hr·ft^2·°F)	0.00
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^2·°F)	
Effective Area (ft^2)	5,453.10
LMTD	0.00
Total Heat Transferred (BTU/hr)	293,637
Surface Effectiveness (Eta)	0.0000
Sensible Heat Transferred (BTU/hr)	293,637
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,942.64	13,564.38
Inlet Temperature (°F)	133.38	122.26
Outlet Temperature (°F)	132.33	126.24
Inlet Specific Humidity	0.020263	
Outlet Specific Humidity	0.020263	
Average Temp (°F)	132.86	124.2458
Skin Temperature (°F)	130.52	127.4947
Velocity ***	5,643.15	0.5309
Reynold's Number	1,564	3,998
Prandtl Number	0.7265	3.4807
Bulk Visc (lbm/ft·hr)	0.0483	1.2943
Skin Visc (lbm/ft·hr)	0.0000	1.2566
Density (lbm/ft^3)	0.0632	61.6447
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0160	0.3714
Relative Humidity In (%)	18.56	
Relative Humidity Out (%)	19.08	

Tube-Side hi (BTU/hr·ft^2·°F)	184.45
j Factor	0.0117
Air-Side ho (BTU/hr·ft^2·°F)	19.56
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^2·°F)	4.68
Effective Area (ft^2)	681.64
LMTD	8.45
Total Heat Transferred (BTU/hr)	26,967
Surface Effectiveness (Eta)	0.8828
Sensible Heat Transferred (BTU/hr)	26,967
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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Att B
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*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% Plug, 5% reduction in air, MAX FF 6/29/05

Extrapolation Calculation for Row 2(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	102,942.64	13,564.38
Inlet Temperature (°F)	132.33	121.11
Outlet Temperature (°F)	131.28	125.11
Inlet Specific Humidity	0.020263	
Outlet Specific Humidity	0.020263	
Average Temp (°F)	131.81	123.1085
Skin Temperature (°F)	129.46	126.4156
Velocity ***	5.643.15	0.5308
Reynold's Number	1.566	3,956
Prandtl Number	0.7265	3.5208
Bulk Visc (lbm/ft·hr)	0.0482	1.3079
Skin Visc (lbm/ft·hr)	0.0000	1.2690
Density (lbm/ft³)	0.0633	61.6629
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3711
Relative Humidity In (%)	19.08	
Relative Humidity Out (%)	19.62	

Tube-Side hi (BTU/hr·ft²·°F)	182.15
j Factor	0.0117
Air-Side ho (BTU/hr·ft²·°F)	19.55
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.07479374
U Overall (BTU/hr·ft²·°F)	4.66
Effective Area (ft²)	681.64
LMTD	8.53
Total Heat Transferred (BTU/hr)	27,113
Surface Effectiveness (Eta)	0.8829
Sensible Heat Transferred (BTU/hr)	27,113
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	102,942.64	13,564.38
Inlet Temperature (°F)	131.28	117.34
Outlet Temperature (°F)	129.99	122.26
Inlet Specific Humidity	0.020263	
Outlet Specific Humidity	0.020263	
Average Temp (°F)	130.63	119.7964
Skin Temperature (°F)	127.75	124.0103
Velocity ***	5.643.15	0.5303
Reynold's Number	1.568	3,836
Prandtl Number	0.7266	3.6421
Bulk Visc (lbm/ft·hr)	0.0482	1.3490
Skin Visc (lbm/ft·hr)	0.0000	1.2971
Density (lbm/ft³)	0.0635	61.7148
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3700
Relative Humidity In (%)	19.62	
Relative Humidity Out (%)	20.30	

Tube-Side hi (BTU/hr·ft²·°F)	175.58
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.54
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.07479374
U Overall (BTU/hr·ft²·°F)	4.60
Effective Area (ft²)	681.64
LMTD	10.64
Total Heat Transferred (BTU/hr)	33,318
Surface Effectiveness (Eta)	0.8829
Sensible Heat Transferred (BTU/hr)	33,318
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% Plug, 5% reduction in air, MAX FF 6/29/05

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	102,942.64	13,564.38	Tube-Side hi (BTU/hr·ft^2·°F)	173.32
Inlet Temperature (°F)	129.99	116.30	j Factor	0.0116
Outlet Temperature (°F)	128.72	121.11	Air-Side ho (BTU/hr·ft^2·°F)	19.53
Inlet Specific Humidity	0.020263		Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Outlet Specific Humidity	0.020263		Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
Average Temp (°F)	129.35	118.7025		
Skin Temperature (°F)	126.53	122.8763	U Overall (BTU/hr·ft^2·°F)	4.57
Velocity ***	5,643.15	0.5302	Effective Area (ft^2)	681.64
Reynold's Number	1,571	3,796	LMTD	10.46
Prandtl Number	0.7267	3.6837	Total Heat Transferred (BTU/hr)	32,584
Bulk Visc (lbm/ft·hr)	0.0481	1.3631		
Skin Visc (lbm/ft·hr)	0.0000	1.3108	Surface Effectiveness (Eta)	0.8830
Density (lbm/ft^3)	0.0636	61.7317	Sensible Heat Transferred (BTU/hr)	32,584
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0159	0.3696	Heat to Condensate (BTU/hr)	
Relative Humidity In (%)	20.30			
Relative Humidity Out (%)	21.00			

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	102,942.64	13,564.38	Tube-Side hi (BTU/hr·ft^2·°F)	164.61
Inlet Temperature (°F)	128.72	111.32	j Factor	0.0116
Outlet Temperature (°F)	127.14	117.34	Air-Side ho (BTU/hr·ft^2·°F)	19.51
Inlet Specific Humidity	0.020263		Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Outlet Specific Humidity	0.020263		Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
Average Temp (°F)	127.93	114.3267		
Skin Temperature (°F)	124.39	119.8243	U Overall (BTU/hr·ft^2·°F)	4.48
Velocity ***	5,643.15	0.5296	Effective Area (ft^2)	681.64
Reynold's Number	1,574	3,640	LMTD	13.36
Prandtl Number	0.7268	3.8580	Total Heat Transferred (BTU/hr)	40,788
Bulk Visc (lbm/ft·hr)	0.0480	1.4218		
Skin Visc (lbm/ft·hr)	0.0000	1.3487	Surface Effectiveness (Eta)	0.8831
Density (lbm/ft^3)	0.0638	61.7975	Sensible Heat Transferred (BTU/hr)	40,788
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0159	0.3681	Heat to Condensate (BTU/hr)	
Relative Humidity In (%)	21.00			
Relative Humidity Out (%)	21.92			

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A+B
Page B10

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

ComEd -- LaSalle

Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% Plug, 5% reduction in air, MAX FF 6/29/05

Extrapolation Calculation for Row 6(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	102,942.64	13,564.38
Inlet Temperature (°F)	127.14	110.60
Outlet Temperature (°F)	125.64	116.30
Inlet Specific Humidity	0.020263	
Outlet Specific Humidity	0.020263	
Average Temp (°F)	126.39	113.4468
Skin Temperature (°F)	123.04	118.7115
Velocity ***	5.643.15	0.5295
Reynold's Number	1.577	3,608
Prandtl Number	0.7270	3.8946
Bulk Visc (lbm/ft·hr)	0.0479	1.4341
Skin Visc (lbm/ft·hr)	0.0000	1.3630
Density (lbm/ft^3)	0.0639	61.8104
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3678
Relative Humidity In (%)	21.92	
Relative Humidity Out (%)	22.83	

Tube-Side hi (BTU/hr·ft^2·°F)	162.74
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.50
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^2·°F)	4.46
Effective Area (ft^2)	681.64
LMTD	12.72
Total Heat Transferred (BTU/hr)	38,623
Surface Effectiveness (Eta)	0.8831
Sensible Heat Transferred (BTU/hr)	38,623
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	102,942.64	13,564.38
Inlet Temperature (°F)	125.64	104.05
Outlet Temperature (°F)	123.72	111.32
Inlet Specific Humidity	0.020263	
Outlet Specific Humidity	0.020263	
Average Temp (°F)	124.68	107.6813
Skin Temperature (°F)	120.41	114.9004
Velocity ***	5.643.15	0.5288
Reynold's Number	1.580	3,406
Prandtl Number	0.7271	4.1497
Bulk Visc (lbm/ft·hr)	0.0478	1.5193
Skin Visc (lbm/ft·hr)	0.0000	1.4138
Density (lbm/ft^3)	0.0642	61.8924
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3657
Relative Humidity In (%)	22.83	
Relative Humidity Out (%)	24.05	

Tube-Side hi (BTU/hr·ft^2·°F)	151.17
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.48
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^2·°F)	4.32
Effective Area (ft^2)	681.64
LMTD	16.72
Total Heat Transferred (BTU/hr)	49,249
Surface Effectiveness (Eta)	0.8832
Sensible Heat Transferred (BTU/hr)	49,249
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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AHB
Page B11

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

ComEd -- LaSalle

Calculation Report for 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% Plug, 5% reduction in air, MAX FF 6/29/05

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	102,942.64	13,564.38
Inlet Temperature (°F)	123.72	103.95
Outlet Temperature (°F)	121.98	110.60
Inlet Specific Humidity	0.020263	
Outlet Specific Humidity	0.020263	
Average Temp (°F)	122.85	107.2752
Skin Temperature (°F)	118.95	113.9127
Velocity ***	5.643.15	0.5288
Reynold's Number	1.584	3,392
Prandtl Number	0.7272	4.1687
Bulk Visc (lbm/ft·hr)	0.0477	1.5256
Skin Visc (lbm/ft·hr)	0.0000	1.4275
Density (lbm/ft^3)	0.0643	61.8981
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3655
Relative Humidity In (%)	24.05	
Relative Humidity Out (%)	25.23	

Tube-Side hi (BTU/hr·ft^2·°F)	150.20
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.46
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^2·°F)	4.31
Effective Area (ft^2)	681.64
LMTD	15.32
Total Heat Transferred (BTU/hr)	44,995
Surface Effectiveness (Eta)	0.8833
Sensible Heat Transferred (BTU/hr)	44,995
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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AH B
Page B12 Final

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

CC-AA-309 - ATTACHMENT 1 - Design Analysis Approval

Page 1 of 2

DESIGN ANALYSIS NO.: Calc. #97-198 **PAGE NO.** 1

Major REV Number: A **Minor Rev Number:** 01

[ ] BRAIDWOOD STATION
[ ] BYRON STATION
[ ] CLINTON STATION
[ ] DRESDEN STATION
[X] LASALLE CO. STATION
[ ] QUAD CITIES STATION

Unit: [ ] 0 [X] 1 [X] 2 [ ] 3

DESCRIPTION CODE:(C018) M10

DISCIPLINE CODE: (C011) M

SYSTEM CODE: (C011) VY

TITLE: VY COOLER THERMAL PERFORMANCE MODEL – 1(2)VY04A

[X] Safety Related [ ] Augmented Quality [ ] Non-Safety Related

ATTRIBUTES (C016)

TYPE	VALUE	TYPE	VALUE
Elevation	694'		
Software	PROTO-HX		

COMPONENT EPN: (C014 Panel)

EPN	TYPE
1VY04A	H15
2VY04A	H15

DOCUMENT NUMBERS: (C012 Panel) (Design Analyses References)

Type/Sub	Document Number	Input (Y/N)
DCD/ EVAL	EC#337494	Y
/		
/		
/		
/		
/		
/		

REMARKS:

CC-AA-309 - ATTACHMENT 1 - Design Analysis Approval
Page 2 of 2

DESIGN ANALYSIS NO. 97-198 **REV:** A01 **PAGE NO.** 2 (2 FINAL)

Revision Summary (including EC's incorporated): Equation 22 (page 18 of Rev. A) in the body of this calculation, indicates Ln, and Ln is the function being used by the program. The "Data Report" output for the air coolers (example Attachment G, page 2) indicates a LOG (base 10) in the "Fin Configuration" equation for the Colburn 'j' factor. A check of the 'j' factor numbers indicated on the computer output in the calculation show that the program is using the natural log Ln. The program manufacturer, Proto-Power, has indicated that the LOG on the Data Report represents indefinite text output and they confirmed that the program is indeed using the natural log (Ln) function for its calculations. (A letter/fax was obtained from Proto-Power on 4-03-02 confirming this discussion. The fax has been assigned file number SEAG 02-000086). A copy of this letter is attached (Attachment A to this minor revision). The calculation results are acceptable as-is.

Electronic Calculation Data Files: Proto-Hx (This data is same as previous minor revision; no computer runs were performed for this minor revision).

(Program Name, Version, File Name extension/size/date/hour/min)

Design impact review completed? [ ] Yes [x] N/A, Per EC#:_337494________
(If yes, attach impact review sheet)

Prepared by: __B._L. Davenport __________/ ____________ / 6-06-02
Print / Sign / Date

Reviewed by: __D. J. Schmit____________/ DJSchmit / 6/10/02
Print / Sign / Date

Method of Review: [✓] Detailed [ ] Alternate [ ] Test

This Design Analysis supersedes: ____________N/A____________ **in its entirety.**

Supplemental Review Required? [ ] Yes [X] No

[ ] Additional Review **[ ] Special Review Team**

Additional Reviewer or Special Review Team Leader: __________/__________/__________
Print / Sign / Date

Special Review Team: (N/A for Additional Review)

Reviewers: 1)__________/__________/__________ 2)__________/__________/__________
Print / Sign / Date / Print / Sign / Date

3)__________/__________/__________ 4)__________/__________/__________
Print / Sign / Date / Print / Sign / Date

Supplemental Review Results:

Approved by: J. T. Conner / ____________ / 6/10/02
Print / Sign / Date

External Design Analysis Review **(Attachment 3 Attached)**

Reviewed by: __________/__________/__________
Print / Sign / Date

Approved by: __________/__________/__________
Print / Sign / Date

Do any ASSUMPTIONS / ENGINEERING JUDGEMENTS require later verification? **[ ] Yes [X] No**
Tracked By: AT#, EC# etc.)____________

DESIGN ANALYSIS 97-198
REV. A01

ATTACHMENT A PAGE A1 OF A1

PROTO-POWER CORPORATION
A Utility Engineering Subsidiary

15 THAMES STREET
GROTON, CT 06340
PH: 860.440.9725
FX: 860.440.8292
www.protopower.com

SEAG Number

02-000086

MEMORANDUM

File No. 908SOF/050119/M02001

To: Brian Davenport

From: Joseph G. Fayan

Date: April 3, 2002

Subject: PROTO-HX Air Coil Module

Brian,

The PROTO-HX Data Sheet Output Report for Air Coils shows the equation for "Configuration (for Air-Side h)" with the "LOG" term in the equation. This in fact represents the "Natural Log" and not "Log Base 10." The equation actually uses the Natural Log (LN) term, however, the output report is ambiguous in printing "LOG".

If you have any other questions, please feel free to give me a call.

Sorry for the confusion.

JGF:baj

CC: Joseph G. Fayan
Job File

REQUEST FOR VOID OF A CALCULATION RESERVATION

PLEASE VOID MY RESERVATION FOR CALCULATION NUMBER 97-198

REVISION A00A

REASON FOR VOID Created in ERROR

PRINT NAME Sylvia F. Venecia

SIGNATURE DATE 6/6/02

6/6/02

h:\wordperf\cancel.wpf

CC-AA-309 - ATTACHMENT 1 - Design Analysis Approval
Page 1 of 2

DESIGN ANALYSIS NO.: Calc. #97-198 **PAGE NO.** 1
Major REV Number: A **Minor Rev Number:** 00

[ ] BRAIDWOOD STATION
[ ] BYRON STATION
[ ] CLINTON STATION
[ ] DRESDEN STATION
[X] LASALLE CO. STATION
[ ] QUAD CITIES STATION
Unit: [ ] 0 [X] 1 [X] 2 [ ] 3

DESCRIPTION CODE:(C018) M10

DISCIPLINE CODE: (C011) M

SYSTEM CODE: (C011) VY

TITLE: VY COOLER THERMAL PERFORMANCE MODEL – 1(2)VY04A

[X] Safety Related [ ] Augmented Quality [ ] Non-Safety Related

ATTRIBUTES (C016)

TYPE	VALUE	TYPE	VALUE
Elevation	694'		
Software	PROTO-HX		

COMPONENT EPN: (C014 Panel)

EPN	TYPE
1VY04A	H15
2VY04A	H15

DOCUMENT NUMBERS: (C012 Panel) (Design Analyses References)

Type/Sub	Document Number	Input (Y/N)
DCD/DCP	EC#334017	Y
/		
/		
/		
/		
/		
/		

REMARKS:

CC-AA-309 - ATTACHMENT 1 - Design Analysis Approval
Page 2 of 2

DESIGN ANALYSIS NO. *97-198* **REV: A00 PAGE NO. 2**

Revision Summary (including EC's incorporated): Updated ProtoHX model for 104°F Service Water inlet temperature and calculated Unit 1 and 2 LPCS Pump Room Cooler thermal margins for design fouling factor and 5% tubes plugged.

Electronic Calculation Data Files: ProtoHX 3.02, vy04a-f.phx, 1088 KB, 4/23/2002, 7:18 pm, vy04a-b.phx, 1088 KB, 4/23/2002, 7:25 pm

(Program Name, Version, File Name extension/size/date/hour/min)

Design impact review completed? [ ] Yes [X] N/A, Per EC#: 334017
(If yes, attach impact review sheet)

Prepared by: Jeff W. VanStrien / _______ / 5-9-02
Print / Sign / Date

Reviewed by: Brian L. Davenport / _______ / 5-10-02
Print / Sign / Date

Method of Review: [X] Detailed [ ] Alternate [ ] Test

This Design Analysis supersedes: N/A **in its entirety.**

Supplemental Review Required? [ ] Yes [X] No

[ ] Additional Review [ ] Special Review Team

Additional Reviewer or Special Review Team Leader: _______ / _______ / _______
Print / Sign / Date

Special Review Team: (N/A for Additional Review)

Reviewers: 1) _______ / _______ / _______ 2) _______ / _______ / _______
Print / Sign / Date Print / Sign / Date

3) _______ / _______ / _______ 4) _______ / _______ / _______
Print / Sign / Date Print / Sign / Date

Supplemental Review Results:

Approved by: S. T. Lenner / _______ / 5/14/02
Print / Sign / Date

External Design Analysis Review (Attachment 3 Attached)

Reviewed by: _______ / _______ / _______
Print / Sign / Date

Approved by: _______ / _______ / _______
Print / Sign / Date

Do any ASSUMPTIONS / ENGINEERING JUDGEMENTS require later verification? [ ] Yes [X] No
Tracked By: AT#, EC# etc.)_______

ComEd

NES-G-14.01
Effective Date:
04/14/00

CALCULATION TABLE OF CONTENTS

CALCULATION NO. *97-198* REV. NO. A00 PAGE NO. 3

E-FORM

1.0 PURPOSE/OBJECTIVE

The purpose of this minor revision is to revise the thermal model of the LPCS Pump Room Coolers (1VY04A, 2VY04A) for a 104°F Service Water inlet temperature. This assessment will evaluate the adequacy of these heat exchangers during a maximum allowable inlet service water temperature of 104°F. Also an acceptable maximum design fouling factor will be determined.

2.0 METHODOLOGY AND ACCEPTANCE CRITERIA

The existing heat exchanger model will be revised by changing the input of the "Tube Inlet Temp." from 100°F to 104°F and simulated for the following conditions: design fouling factor and design fouling factor with 5% of the tubes plugged. The acceptance criteria will be for the thermal margin at each stated condition to exceed the LaSalle design heat load of 633,288 BTU/hr (Ref.1, Table 1). Additional conservatism was built into this acceptance criteria by assuming a 5% uncertainty in the Proto-HX heat transfer calculations. The original benchmark model developed for this heat exchanger demonstrated a correlation to vendor performance specification well within this assumed 5% margin.

A final case will be evaluated which determines the maximum acceptable fouling factor at which the design heat load can be accommodated including heat transfer model uncertainty and a 5% tube plugging allowance.

3.0 ASSUMPTIONS / ENGINEERING JUDGMENTS

The assumptions indicated in section 5.0 of Reference 1 are still valid.

4.0 DESIGN INPUTS

The design inputs consist of References 1 listed below.

5.0 REFERENCES

1. Calculation No. 97-198, Rev. A, "Thermal Model of COMED / LaSalle Station Unit 1 and 2 LPCS Pump Room Coolers."

6.0 CALCULATIONS

The current calculation model is based on a Service Water inlet temperature of 100°F with varying cooling water flow rates. Based on Reference 1 Calculations, the limiting flow rate for this unit is 66.5 gpm. At this flow rate, temperature and at an assumed overall fouling factor of 0.03171750 hr*ft^2*°F/BTU, the amount of heat transferred is 818,271 BTU/hr compared with a LaSalle Station Design Heat Load of 633,288 BTU/hr giving a 29.2% thermal margin (Ref. 1, Table 10).

Thermal margin is calculated by the following method:

Required Heat Load - Calculated Heat Transfer = Thermal Margin [Equation 1]

To express this as a percent of the required heat load, the following method is used:

$$\frac{ThermalM\arg in}{\mathrm{Re}\,quiredHeatLoad}\times 100\% = \%ThermalM\arg in \qquad \text{[Equation 2]}$$

When the service water inlet temperature is increased to 104°F for the same limiting flow rate, but with a design fouling factor of 0.02228812 hr*ft2*°F/BTU, the heat transfer reduces to 759,971 BTU/hr which represents a 20% thermal margin over the required heat transfer of 633,288 BTU/hr [Attachment A]. With a plugging allowance of 5% of the total tubes in the heat exchanger and running the model again at the design fouling factor and 104°F inlet temperature resulted in a 758,635 BTU/hr heat transfer, a 19.8% thermal margin above the design heat load [Attachment B]. The maximum fouling factor (at 104°F & 5% plugged) was found to be 0.005 hr*ft^2*°F/BTU tube-side and 0.0005 hr*ft^2*°F/BTU air-side (0.07479374 hr*ft^2*°F/BTU overall) [Attachment C].

CALCULATION PAGE

CALCULATION NO. *97-198*	REV. NO. A00	PAGE NO. 6 of 6

7.0 SUMMARY AND CONCLUSIONS

The LPCS Pump Room Cooler Model was found to have adequate thermal margin for a maximum lake temperature of 104°F when operated at design fouling conditions. The maximum fouling factor was found to be 0.005 hr*ft^{2}*°F/BTU tube-side and 0.0005 hr*ft^{2}*°F/BTU air-side (0.07479374 hr*ft^{2}*°F/BTU overall) while maintaining the required heat transfer rate at 104°F inlet temperature and with a 5% plugging allowance.

8.0 ATTACHMENTS:

Attachment "A" – Proto-Hx Calc. Report for 1(2)VY04A
(CSCS=104°F @ Design Fouling)
Attachment "B" – Proto-Hx Calc. Report for 1(2)VY04A
(CSCS=104°F @ Design FF, w/ 5% plugged)
Attachment "C" – Proto-Hx Calc. Report for 1(2)VY04A
(CSCS=104°F @ Max. Allowable FF, w/ 5% plugged)

Final Page
(Last Page)

E-FORM

ComEd

CALCULATION NO.
97-198
REVISION NO. A00

PAGE NO. A1 of A14

Attachment "A"

Proto-Hx Calc. Report for 1(2)VY04A
(CSCS=104°F @ Design Fouling)

E-FORM

18:22:40 **PROTO-HX 3.01 by Proto-Power Corporation (SN#663-7371)** 04/23/02
ComEd -- LaSalle
Data Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils
VY04 @ 104 F, DESIGN FF [FRONT]

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	33,546.00 acfm	118.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle VY Cooler 04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils
VY04 @ 104 F, DESIGN FF [FRONT]

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	39.20
Air Flow (acfm)	29,321.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, DESIGN FF [FRONT]

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,350.99	19,475.71
Inlet Temperature (°F)	148.00	104.00
Outlet Temperature (°F)	130.98	127.69
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	2,870.05
LMTD	
Total Heat Transferred (BTU/hr)	461,273
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	461,273
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,350.99	19,475.71
Inlet Temperature (°F)	148.00	117.29
Outlet Temperature (°F)	143.76	129.09
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	145.88	123.19
Skin Temperature (°F)	135.56	131.86
Velocity ***	5,642.64	0.72
Reynold's Number	2,050	5,400
Prandtl Number	0.7253	3.5179
Bulk Visc (lbm/ft·hr)	0.0491	1.3070
Skin Visc (lbm/ft·hr)		1.2089
Density (lbm/ft³)	0.0620	61.6616
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0163	0.3711

Tube-Side hi (BTU/hr·ft²·°F)	281.55
j Factor	0.0106
Air-Side ho (BTU/hr·ft²·°F)	17.84
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	7.24
Effective Area (ft²)	717.51
LMTD	22.12
Total Heat Transferred (BTU/hr)	114,846
Surface Effectiveness (Eta)	0.8917
Sensible Heat Transferred (BTU/hr)	114,846
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,350.99	19,475.71
Inlet Temperature (°F)	143.76	115.49
Outlet Temperature (°F)	139.89	126.29
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	141.83	120.89
Skin Temperature (°F)	132.37	128.99
Velocity ***	5,642.64	0.72
Reynold's Number	2,061	5,286
Prandtl Number	0.7257	3.6013
Bulk Visc (lbm/ft·hr)	0.0489	1.3352
Skin Visc (lbm/ft·hr)		1.2399
Density (lbm/ft³)	0.0624	61.6978
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3703

Tube-Side hi (BTU/hr·ft²·°F)	275.29
j Factor	0.0106
Air-Side ho (BTU/hr·ft²·°F)	17.80
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	7.17
Effective Area (ft²)	717.51
LMTD	20.42
Total Heat Transferred (BTU/hr)	105,010
Surface Effectiveness (Eta)	0.8919
Sensible Heat Transferred (BTU/hr)	105,010
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,350.99	19,475.71
Inlet Temperature (°F)	139.89	103.96
Outlet Temperature (°F)	135.11	117.29
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	137.50	110.62
Skin Temperature (°F)	125.83	121.66
Velocity ***	5,642.64	0.72
Reynold's Number	2,072	4,786
Prandtl Number	0.7261	4.0164
Bulk Visc (lbm/ft·hr)	0.0486	1.4748
Skin Visc (lbm/ft·hr)		1.3257
Density (lbm/ft³)	0.0629	61.8512
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3668

Tube-Side hi (BTU/hr·ft²·°F)	248.93
j Factor	0.0106
Air-Side ho (BTU/hr·ft²·°F)	17.76
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	6.88
Effective Area (ft²)	717.51
LMTD	26.26
Total Heat Transferred (BTU/hr)	129,631
Surface Effectiveness (Eta)	0.8921
Sensible Heat Transferred (BTU/hr)	129,631
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,350.99	19,475.71
Inlet Temperature (°F)	135.11	104.00
Outlet Temperature (°F)	130.98	115.49
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	133.04	109.74
Skin Temperature (°F)	122.96	119.37
Velocity ***	5,642.64	0.72
Reynold's Number	2,084	4,744
Prandtl Number	0.7264	4.0554
Bulk Visc (lbm/ft·hr)	0.0483	1.4878
Skin Visc (lbm/ft·hr)		1.3545
Density (lbm/ft^3)	0.0634	61.8636
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3664

Tube-Side hi (BTU/hr·ft^2·°F)	246.12
j Factor	0.0106
Air-Side ho (BTU/hr·ft^2·°F)	17.72
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	6.84
Effective Area (ft^2)	717.51
LMTD	22.77
Total Heat Transferred (BTU/hr)	111,787
Surface Effectiveness (Eta)	0.8923
Sensible Heat Transferred (BTU/hr)	111,787
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Inlet Air Flowrate Calculator - 1(2)VY04A [front]
Relative Humidity Calculator - 1(2)VY04A [back]

Total P:	P=		14.315	psia	Inlet Air Flow
Dry Bulb T OUT:	T=		130.98	F	29321 acfm
Specific Hum.:	W =		0.020273629		
H2O Vap P:	Pv = (W*Rv*P)/(Ra+(W*Rv) =		0.451874527	psia	
		Rv =	85.778	(ft-lbf)/(lbm-R)	
		Ra =	53.352	(ft-lbf)/(lbm-R)	
Dry Air P:	Pa = P - Pv =		13.86312547	psia	
Dry Air rho OUT:	rho a = (144/Ra)*(Pa/(459.67+T) =		0.0633	lbm/ft^3	
Dry Air rho IN:	rho a = (144/Ra)*(Pa/(459.67+T) =		0.061575	lbm/ft^3	
Dry Bulb T IN:	T=		148	F	
Outlet Air Flow:	V =		28500	cfm	
Sat Air P:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$		2.28	psia	
Moist Air Rel. Humidity:	RH = Pv/Ps =		19.78%		
Equation Coeff.:	a =		2.358607E-02		
	b =		1.007276E-03		
	c =		1.888033E-05		
	d =		3.775047E-07		
	e =		4.871208E-10		
	f =		2.109071E-11		

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Data Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, DESIGN FF [BACK]

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	32,483.00 acfm	82.00 gpm
Inlet Dry Bulb Temp	°F	105.00 °F
Inlet Wet Bulb Temp	°F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
VY04 @ 104 F, DESIGN FF [BACK]

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	27.30
Air Flow (acfm)	28,500.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	131.0
Inlet Relative Humidity (%)	19.78
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, DESIGN FF [BACK]

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,352.49	13,563.44
Inlet Temperature (°F)	130.98	104.00
Outlet Temperature (°F)	119.96	126.06
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	5,740.10
LMTD	
Total Heat Transferred (BTU/hr)	298,698
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	298,698
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,352.49	13,563.44
Inlet Temperature (°F)	130.98	123.10
Outlet Temperature (°F)	130.11	126.59
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	130.54	124.85
Skin Temperature (°F)	128.57	127.80
Velocity ***	5,642.72	0.50
Reynold's Number	1,568	3,819
Prandtl Number	0.7266	3.4599
Bulk Visc (lbm/ft·hr)	0.0482	1.2872
Skin Visc (lbm/ft·hr)		1.2533
Density (lbm/ft³)	0.0635	61.6350
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3716

Tube-Side hi (BTU/hr·ft²·°F)	171.91
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.54
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	5.99
Effective Area (ft²)	717.51
LMTD	5.51
Total Heat Transferred (BTU/hr)	23,662
Surface Effectiveness (Eta)	0.8829
Sensible Heat Transferred (BTU/hr)	23,662
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	108,352.49	13,563.44
Inlet Temperature (°F)	130.11	121.90
Outlet Temperature (°F)	129.20	125.52
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	129.65	123.71
Skin Temperature (°F)	127.60	126.80
Velocity ***	5,642.72	0.50
Reynold's Number	1,570	3,779
Prandtl Number	0.7267	3.4996
Bulk Visc (lbm/ft·hr)	0.0481	1.3007
Skin Visc (lbm/ft·hr)		1.2645
Density (lbm/ft^3)	0.0636	61.6533
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3713

Tube-Side hi (BTU/hr·ft^2·°F)	169.71
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.53
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	5.95
Effective Area (ft^2)	717.51
LMTD	5.75
Total Heat Transferred (BTU/hr)	24,543
Surface Effectiveness (Eta)	0.8830
Sensible Heat Transferred (BTU/hr)	24,543
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	108,352.49	13,563.44
Inlet Temperature (°F)	129.20	118.38
Outlet Temperature (°F)	128.02	123.10
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	128.61	120.74
Skin Temperature (°F)	125.94	124.91
Velocity ***	5,642.72	0.50
Reynold's Number	1,572	3,676
Prandtl Number	0.7268	3.6068
Bulk Visc (lbm/ft·hr)	0.0480	1.3371
Skin Visc (lbm/ft·hr)		1.2865
Density (lbm/ft^3)	0.0637	61.7001
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3703

Tube-Side hi (BTU/hr·ft^2·°F)	164.13
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.52
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	5.85
Effective Area (ft^2)	717.51
LMTD	7.62
Total Heat Transferred (BTU/hr)	31,949
Surface Effectiveness (Eta)	0.8830
Sensible Heat Transferred (BTU/hr)	31,949
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
VY04 @ 104 F, DESIGN FF [BACK]

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,352.49	13,563.44
Inlet Temperature (°F)	128.02	117.20
Outlet Temperature (°F)	126.85	121.90
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	127.44	119.55
Skin Temperature (°F)	124.78	123.75
Velocity ***	5,642.72	0.50
Reynold's Number	1,575	3,635
Prandtl Number	0.7269	3.6514
Bulk Visc (lbm/ft·hr)	0.0480	1.3522
Skin Visc (lbm/ft·hr)		1.3002
Density (lbm/ft^3)	0.0638	61.7186
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3699

Tube-Side hi (BTU/hr·ft^2·°F)	161.79
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.51
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	5.80
Effective Area (ft^2)	717.51
LMTD	7.64
Total Heat Transferred (BTU/hr)	31,781
Surface Effectiveness (Eta)	0.8831
Sensible Heat Transferred (BTU/hr)	31,781
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,352.49	13,563.44
Inlet Temperature (°F)	126.85	112.11
Outlet Temperature (°F)	125.28	118.38
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	126.07	115.25
Skin Temperature (°F)	122.52	121.15
Velocity ***	5,642.72	0.50
Reynold's Number	1,577	3,488
Prandtl Number	0.7270	3.8202
Bulk Visc (lbm/ft·hr)	0.0479	1.4091
Skin Visc (lbm/ft·hr)		1.3320
Density (lbm/ft^3)	0.0640	61.7838
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3684

Tube-Side hi (BTU/hr·ft^2·°F)	153.65
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.49
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	5.64
Effective Area (ft^2)	717.51
LMTD	10.49
Total Heat Transferred (BTU/hr)	42,461
Surface Effectiveness (Eta)	0.8832
Sensible Heat Transferred (BTU/hr)	42,461
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,352.49	13,563.44
Inlet Temperature (°F)	125.28	111.28
Outlet Temperature (°F)	123.80	117.20
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	124.54	114.24
Skin Temperature (°F)	121.19	119.89
Velocity ***	5,642.72	0.50
Reynold's Number	1,581	3,454
Prandtl Number	0.7271	3.8616
Bulk Visc (lbm/ft·hr)	0.0478	1.4230
Skin Visc (lbm/ft·hr)		1.3478
Density (lbm/ft³)	0.0641	61.7988
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3681

Tube-Side hi (BTU/hr·ft²·°F)	151.60
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.48
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	5.60
Effective Area (ft²)	717.51
LMTD	10.00
Total Heat Transferred (BTU/hr)	40,153
Surface Effectiveness (Eta)	0.8832
Sensible Heat Transferred (BTU/hr)	40,153
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,352.49	13,563.44
Inlet Temperature (°F)	123.80	103.99
Outlet Temperature (°F)	121.77	112.11
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	122.79	108.05
Skin Temperature (°F)	118.20	116.43
Velocity ***	5,642.72	0.50
Reynold's Number	1,584	3,248
Prandtl Number	0.7272	4.1324
Bulk Visc (lbm/ft·hr)	0.0477	1.5135
Skin Visc (lbm/ft·hr)		1.3930
Density (lbm/ft³)	0.0644	61.8873
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3658

Tube-Side hi (BTU/hr·ft²·°F)	139.79
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.46
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	5.35
Effective Area (ft²)	717.51
LMTD	14.33
Total Heat Transferred (BTU/hr)	55,001
Surface Effectiveness (Eta)	0.8833
Sensible Heat Transferred (BTU/hr)	55,001
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

18:30:55 **PROTO-HX 3.01 by Proto-Power Corporation (SN#663-7371)** 04/23/02

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, DESIGN FF [BACK]

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,352.49	13,563.44
Inlet Temperature (°F)	121.77	104.02
Outlet Temperature (°F)	119.96	111.28
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	120.87	107.65
Skin Temperature (°F)	116.77	115.18
Velocity ***	5,642.72	0.50
Reynold's Number	1,588	3,234
Prandtl Number	0.7274	4.1513
Bulk Visc (lbm/ft·hr)	0.0475	1.5198
Skin Visc (lbm/ft·hr)		1.4100
Density (lbm/ft³)	0.0646	61.8929
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3657

Tube-Side hi (BTU/hr·ft²·°F)	138.82
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.44
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	5.32
Effective Area (ft²)	717.51
LMTD	12.86
Total Heat Transferred (BTU/hr)	49,148
Surface Effectiveness (Eta)	0.8834
Sensible Heat Transferred (BTU/hr)	49,148
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment "B"

Proto-Hx Calc. Report for 1(2)VY04A
(CSCS=104°F @ Design FF, w/ 5% plugged)

E-FORM

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Data Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils
VY04 @ 104 F, 5% PLUG, DESIGN FF

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	33,546.00 acfm	118.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle VY Cooler 04A
	j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	19.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% PLUG, DESIGN FF

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	39.20
Air Flow (acfm)	29,316.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% PLUG, DESIGN FF

Extrapolation Calculation Summary

	Air-Side	**Tube-Side**		
Mass Flow (lbm/hr)	108,332.51	19,475.71	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	148.00	104.00	j Factor	
Outlet Temperature (°F)	131.09	127.57	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	2,726.55
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	458,168
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	458,168
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	**Tube-Side**		
Mass Flow (lbm/hr)	108,332.51	19,475.71	Tube-Side hi (BTU/hr·ft^2·°F)	300.31
Inlet Temperature (°F)	148.00	117.26	j Factor	0.0104
Outlet Temperature (°F)	143.80	128.96	Air-Side ho (BTU/hr·ft^2·°F)	18.45
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	145.90	123.11		
Skin Temperature (°F)	135.45	131.59	U Overall (BTU/hr·ft^2·°F)	7.52
Velocity ***	5,938.61	0.76	Effective Area (ft^2)	681.64
Reynold's Number	2,158	5,680	LMTD	22.23
Prandtl Number	0.7253	3.5208	Total Heat Transferred (BTU/hr)	113,890
Bulk Visc (lbm/ft·hr)	0.0491	1.3079		
Skin Visc (lbm/ft·hr)		1.2118	Surface Effectiveness (Eta)	0.8885
Density (lbm/ft^3)	0.0620	61.6628	Sensible Heat Transferred (BTU/hr)	113,890
Cp (BTU/lbm·°F)	0.2402	0.9990	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3711	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% PLUG, DESIGN FF

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	108,332.51	19,475.71	Tube-Side hi (BTU/hr·ft²·°F)	293.78
Inlet Temperature (°F)	143.80	115.44	j Factor	0.0104
Outlet Temperature (°F)	139.95	126.17	Air-Side ho (BTU/hr·ft²·°F)	18.41
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	141.87	120.81		
Skin Temperature (°F)	132.28	128.74	U Overall (BTU/hr·ft²·°F)	7.45
Velocity ***	5,938.61	0.76	Effective Area (ft²)	681.64
Reynold's Number	2,169	5,560	LMTD	20.55
Prandtl Number	0.7257	3.6044	Total Heat Transferred (BTU/hr)	104,374
Bulk Visc (lbm/ft·hr)	0.0489	1.3363		
Skin Visc (lbm/ft·hr)		1.2427	Surface Effectiveness (Eta)	0.8887
Density (lbm/ft³)	0.0624	61.6991	Sensible Heat Transferred (BTU/hr)	104,374
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0162	0.3703	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	108,332.51	19,475.71	Tube-Side hi (BTU/hr·ft²·°F)	266.60
Inlet Temperature (°F)	139.95	104.03	j Factor	0.0104
Outlet Temperature (°F)	135.20	117.26	Air-Side ho (BTU/hr·ft²·°F)	18.37
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	137.57	110.64		
Skin Temperature (°F)	125.75	121.40	U Overall (BTU/hr·ft²·°F)	7.17
Velocity ***	5,938.61	0.76	Effective Area (ft²)	681.64
Reynold's Number	2,181	5,039	LMTD	26.32
Prandtl Number	0.7261	4.0154	Total Heat Transferred (BTU/hr)	128,606
Bulk Visc (lbm/ft·hr)	0.0486	1.4745		
Skin Visc (lbm/ft·hr)		1.3288	Surface Effectiveness (Eta)	0.8890
Density (lbm/ft³)	0.0629	61.8509	Sensible Heat Transferred (BTU/hr)	128,606
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0161	0.3668	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% PLUG, DESIGN FF

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,332.51	19,475.71
Inlet Temperature (°F)	135.20	104.00
Outlet Temperature (°F)	131.09	115.44
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	133.15	109.72
Skin Temperature (°F)	122.90	119.13
Velocity ***	5,938.61	0.76
Reynold's Number	2,193	4,992
Prandtl Number	0.7264	4.0566
Bulk Visc (lbm/ft·hr)	0.0483	1.4882
Skin Visc (lbm/ft·hr)		1.3575
Density (lbm/ft³)	0.0634	61.8640
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3664

Tube-Side hi (BTU/hr·ft²·°F)	263.55
j Factor	0.0104
Air-Side ho (BTU/hr·ft²·°F)	18.33
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	7.13
Effective Area (ft²)	681.64
LMTD	22.91
Total Heat Transferred (BTU/hr)	111,298
Surface Effectiveness (Eta)	0.8892
Sensible Heat Transferred (BTU/hr)	111,298
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Inlet Air Flowrate Calculator - 1(2)VY04A [front]
Relative Humidity Calculator - 1(2)VY04A [back]

Total P:	P=	14.315	psia	Inlet Air Flow
Dry Bulb T OUT:	T=	131.09	F	29316 acfm
Specific Hum.:	W =	0.020273629		
H2O Vap P:	Pv = (W*Rv*P)/(Ra+(W*Rv) =	0.451874527	psia	
	Rv =	85.778	(ft-lbf)/(lbm-R)	
	Ra =	53.352	(ft-lbf)/(lbm-R)	
Dry Air P:	Pa = P - Pv =	13.86312547	psia	
Dry Air rho OUT:	rho a = (144/Ra)*(Pa/(459.67+T) =	0.0633	lbm/ft^3	
Dry Air rho IN:	rho a = (144/Ra)*(Pa/(459.67+T) =	0.061575	lbm/ft^3	
Dry Bulb T IN:	T=	148	F	
Outlet Air Flow:	V =	28500	cfm	
Sat Air P:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	2.29	psia	
Moist Air Rel. Humidity:	RH = Pv/Ps =	19.73%		
Equation Coeff.:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

Data Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
VY04 @ 104 F, 5% PLUG, DESIGN FF

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	32,483.00 acfm	82.00 gpm
Inlet Dry Bulb Temp	°F	105.00 °F
Inlet Wet Bulb Temp	°F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	19.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
VY04 @ 104 F, 5% PLUG, DESIGN FF

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	27.30
Air Flow (acfm)	28,500.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	131.1
Inlet Relative Humidity (%)	19.73
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% PLUG, DESIGN FF

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,330.92	13,563.44
Inlet Temperature (°F)	131.09	104.00
Outlet Temperature (°F)	120.00	126.15
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	5,453.10
LMTD	
Total Heat Transferred (BTU/hr)	300,467
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	300,467
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,330.92	13,563.44
Inlet Temperature (°F)	131.09	123.19
Outlet Temperature (°F)	130.22	126.69
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	130.65	124.94
Skin Temperature (°F)	128.63	127.82
Velocity ***	5,938.52	0.53
Reynold's Number	1,650	4,023
Prandtl Number	0.7266	3.4565
Bulk Visc (lbm/ft·hr)	0.0482	1.2861
Skin Visc (lbm/ft·hr)		1.2530
Density (lbm/ft³)	0.0634	61.6335
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3717

Tube-Side hi (BTU/hr·ft²·°F)	185.77
j Factor	0.0114
Air-Side ho (BTU/hr·ft²·°F)	20.21
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	6.30
Effective Area (ft²)	681.64
LMTD	5.52
Total Heat Transferred (BTU/hr)	23,686
Surface Effectiveness (Eta)	0.8796
Sensible Heat Transferred (BTU/hr)	23,686
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,330.92	13,563.44
Inlet Temperature (°F)	130.22	121.98
Outlet Temperature (°F)	129.31	125.61
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	129.76	123.79
Skin Temperature (°F)	127.66	126.82
Velocity ***	5,938.52	0.53
Reynold's Number	1,652	3,981
Prandtl Number	0.7267	3.4966
Bulk Visc (lbm/ft·hr)	0.0481	1.2997
Skin Visc (lbm/ft·hr)		1.2643
Density (lbm/ft³)	0.0635	61.6519
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3713

Tube-Side hi (BTU/hr·ft²·°F)	183.46
j Factor	0.0114
Air-Side ho (BTU/hr·ft²·°F)	20.20
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	6.26
Effective Area (ft²)	681.64
LMTD	5.77
Total Heat Transferred (BTU/hr)	24,610
Surface Effectiveness (Eta)	0.8796
Sensible Heat Transferred (BTU/hr)	24,610
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,330.92	13,563.44
Inlet Temperature (°F)	129.31	118.47
Outlet Temperature (°F)	128.13	123.19
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	128.72	120.83
Skin Temperature (°F)	125.98	124.89
Velocity ***	5,938.52	0.53
Reynold's Number	1,654	3,873
Prandtl Number	0.7268	3.6035
Bulk Visc (lbm/ft·hr)	0.0480	1.3360
Skin Visc (lbm/ft·hr)		1.2867
Density (lbm/ft³)	0.0637	61.6987
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3703

Tube-Side hi (BTU/hr·ft²·°F)	177.64
j Factor	0.0114
Air-Side ho (BTU/hr·ft²·°F)	20.19
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	6.15
Effective Area (ft²)	681.64
LMTD	7.63
Total Heat Transferred (BTU/hr)	32,014
Surface Effectiveness (Eta)	0.8797
Sensible Heat Transferred (BTU/hr)	32,014
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% PLUG, DESIGN FF

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	108,330.92	13,563.44	Tube-Side hi (BTU/hr·ft^2·°F)	175.17
Inlet Temperature (°F)	128.13	117.26	j Factor	0.0114
Outlet Temperature (°F)	126.95	121.98	Air-Side ho (BTU/hr·ft^2·°F)	20.17
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	127.54	119.62		
Skin Temperature (°F)	124.81	123.72	U Overall (BTU/hr·ft^2·°F)	6.11
Velocity ***	5,938.52	0.53	Effective Area (ft^2)	681.64
Reynold's Number	1,657	3,829	LMTD	7.67
Prandtl Number	0.7269	3.6487	Total Heat Transferred (BTU/hr)	31,920
Bulk Visc (lbm/ft·hr)	0.0480	1.3513		
Skin Visc (lbm/ft·hr)		1.3006	Surface Effectiveness (Eta)	0.8797
Density (lbm/ft^3)	0.0638	61.7175	Sensible Heat Transferred (BTU/hr)	31,920
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0159	0.3699	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	108,330.92	13,563.44	Tube-Side hi (BTU/hr·ft^2·°F)	166.69
Inlet Temperature (°F)	126.95	112.17	j Factor	0.0114
Outlet Temperature (°F)	125.38	118.47	Air-Side ho (BTU/hr·ft^2·°F)	20.16
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	126.16	115.32		
Skin Temperature (°F)	122.52	121.07	U Overall (BTU/hr·ft^2·°F)	5.95
Velocity ***	5,938.52	0.53	Effective Area (ft^2)	681.64
Reynold's Number	1,660	3,675	LMTD	10.51
Prandtl Number	0.7270	3.8172	Total Heat Transferred (BTU/hr)	42,647
Bulk Visc (lbm/ft·hr)	0.0479	1.4081		
Skin Visc (lbm/ft·hr)		1.3330	Surface Effectiveness (Eta)	0.8798
Density (lbm/ft^3)	0.0640	61.7828	Sensible Heat Transferred (BTU/hr)	42,647
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0158	0.3684	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,330.92	13,563.44
Inlet Temperature (°F)	125.38	111.29
Outlet Temperature (°F)	123.88	117.26
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	124.63	114.28
Skin Temperature (°F)	121.18	119.80
Velocity ***	5,938.52	0.53
Reynold's Number	1,663	3,638
Prandtl Number	0.7271	3.8599
Bulk Visc (lbm/ft·hr)	0.0478	1.4224
Skin Visc (lbm/ft·hr)		1.3490
Density (lbm/ft³)	0.0641	61.7982
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3681

Tube-Side hi (BTU/hr·ft²·°F)	164.49
j Factor	0.0114
Air-Side ho (BTU/hr·ft²·°F)	20.14
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	5.91
Effective Area (ft²)	681.64
LMTD	10.04
Total Heat Transferred (BTU/hr)	40,433
Surface Effectiveness (Eta)	0.8799
Sensible Heat Transferred (BTU/hr)	40,433
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	108,330.92	13,563.44
Inlet Temperature (°F)	123.88	103.98
Outlet Temperature (°F)	121.84	112.17
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	122.86	108.08
Skin Temperature (°F)	118.13	116.25
Velocity ***	5,938.52	0.53
Reynold's Number	1,667	3,419
Prandtl Number	0.7272	4.1313
Bulk Visc (lbm/ft·hr)	0.0477	1.5131
Skin Visc (lbm/ft·hr)		1.3955
Density (lbm/ft³)	0.0644	61.8869
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3658

Tube-Side hi (BTU/hr·ft²·°F)	152.18
j Factor	0.0114
Air-Side ho (BTU/hr·ft²·°F)	20.12
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	5.66
Effective Area (ft²)	681.64
LMTD	14.38
Total Heat Transferred (BTU/hr)	55,478
Surface Effectiveness (Eta)	0.8800
Sensible Heat Transferred (BTU/hr)	55,478
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	108,330.92	13,563.44
Inlet Temperature (°F)	121.84	103.96
Outlet Temperature (°F)	120.00	111.29
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	120.92	107.63
Skin Temperature (°F)	116.68	115.00
Velocity ***	5,938.52	0.53
Reynold's Number	1,671	3,404
Prandtl Number	0.7273	4.1522
Bulk Visc (lbm/ft·hr)	0.0475	1.5201
Skin Visc (lbm/ft·hr)		1.4125
Density (lbm/ft³)	0.0646	61.8932
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3657

Tube-Side hi (BTU/hr·ft²·°F)	151.07
j Factor	0.0114
Air-Side ho (BTU/hr·ft²·°F)	20.10
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	5.64
Effective Area (ft²)	681.64
LMTD	12.93
Total Heat Transferred (BTU/hr)	49,680
Surface Effectiveness (Eta)	0.8801
Sensible Heat Transferred (BTU/hr)	49,680
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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97-198
REVISION NO. A00

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Attachment "C"

Proto-Hx Calc. Report for 1(2)VY04A
(CSCS=104°F @ Max. Allowable FF, w/ 5% plugged)

E-FORM

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Data Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils
VY04 @ 104 F, 5% PLUG, MAX FF

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	33,546.00 acfm	118.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.005000
Air-Side Fouling	0.000500
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle VY Cooler 04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	19.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% PLUG, MAX FF

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	39.20
Air Flow (acfm)	29,179.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils
VY04 @ 104 F, 5% PLUG, MAX FF

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	107,826.25	19,475.71
Inlet Temperature (°F)	148.00	104.00
Outlet Temperature (°F)	133.86	123.60
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.07479374
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	2,726.55
LMTD	
Total Heat Transferred (BTU/hr)	381,356
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	381,356
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	107,826.25	19,475.71
Inlet Temperature (°F)	148.00	114.72
Outlet Temperature (°F)	144.46	124.54
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	146.23	119.63
Skin Temperature (°F)	137.55	126.89
Velocity ***	5,910.86	0.76
Reynold's Number	2,147	5,499
Prandtl Number	0.7253	3.6484
Bulk Visc (lbm/ft·hr)	0.0491	1.3512
Skin Visc (lbm/ft·hr)		1.2635
Density (lbm/ft³)	0.0620	61.7174
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0163	0.3699

Tube-Side hi (BTU/hr·ft²·°F)	290.29
j Factor	0.0105
Air-Side ho (BTU/hr·ft²·°F)	18.39
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.07479374
U Overall (BTU/hr·ft²·°F)	5.34
Effective Area (ft²)	681.64
LMTD	26.26
Total Heat Transferred (BTU/hr)	95,530
Surface Effectiveness (Eta)	0.8888
Sensible Heat Transferred (BTU/hr)	95,530
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	107,826.25	19,475.71
Inlet Temperature (°F)	144.46	113.59
Outlet Temperature (°F)	141.19	122.66
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	142.82	118.12
Skin Temperature (°F)	134.79	124.94
Velocity ***	5,910.86	0.76
Reynold's Number	2,156	5,421
Prandtl Number	0.7256	3.7059
Bulk Visc (lbm/ft·hr)	0.0489	1.3706
Skin Visc (lbm/ft·hr)		1.2861
Density (lbm/ft^3)	0.0623	61.7405
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3694

Tube-Side hi (BTU/hr·ft^2·°F)	285.98
j Factor	0.0104
Air-Side ho (BTU/hr·ft^2·°F)	18.36
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^2·°F)	5.31
Effective Area (ft^2)	681.64
LMTD	24.39
Total Heat Transferred (BTU/hr)	88,293
Surface Effectiveness (Eta)	0.8890
Sensible Heat Transferred (BTU/hr)	88,293
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	107,826.25	19,475.71
Inlet Temperature (°F)	141.19	103.99
Outlet Temperature (°F)	137.32	114.72
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	139.25	109.35
Skin Temperature (°F)	129.75	118.13
Velocity ***	5,910.86	0.76
Reynold's Number	2,166	4,974
Prandtl Number	0.7259	4.0729
Bulk Visc (lbm/ft·hr)	0.0487	1.4937
Skin Visc (lbm/ft·hr)		1.3705
Density (lbm/ft^3)	0.0627	61.8691
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0161	0.3663

Tube-Side hi (BTU/hr·ft^2·°F)	262.31
j Factor	0.0104
Air-Side ho (BTU/hr·ft^2·°F)	18.33
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^2·°F)	5.18
Effective Area (ft^2)	681.64
LMTD	29.54
Total Heat Transferred (BTU/hr)	104,292
Surface Effectiveness (Eta)	0.8892
Sensible Heat Transferred (BTU/hr)	104,292
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	107,826.25	19,475.71
Inlet Temperature (°F)	137.32	104.00
Outlet Temperature (°F)	133.86	113.59
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	135.59	108.79
Skin Temperature (°F)	127.08	116.69
Velocity ***	5,910.86	0.76
Reynold's Number	2,176	4,946
Prandtl Number	0.7262	4.0985
Bulk Visc (lbm/ft·hr)	0.0485	1.5022
Skin Visc (lbm/ft·hr)		1.3895
Density (lbm/ft³)	0.0631	61.8770
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3661

Tube-Side hi (BTU/hr·ft²·°F)	260.43
j Factor	0.0104
Air-Side ho (BTU/hr·ft²·°F)	18.29
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.07479374
U Overall (BTU/hr·ft²·°F)	5.17
Effective Area (ft²)	681.64
LMTD	26.48
Total Heat Transferred (BTU/hr)	93,241
Surface Effectiveness (Eta)	0.8893
Sensible Heat Transferred (BTU/hr)	93,241
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Inlet Air Flowrate Calculator - 1(2)VY04A [front]
Relative Humidity Calculator - 1(2)VY04A [back]

Total P:	P=		14.315	psia	Inlet Air Flow
Dry Bulb T OUT:	T=		133.86	F	29179 acfm
Specific Hum.:	W =		0.020273629		
H2O Vap P:	Pv = (W*Rv*P)/(Ra+(W*Rv) =		0.451874527	psia	
		Rv =	85.778	(ft-lbf)/(lbm-R)	
		Ra =	53.352	(ft-lbf)/(lbm-R)	
Dry Air P:	Pa = P - Pv =		13.86312547	psia	
Dry Air rho OUT:	rho a = (144/Ra)*(Pa/(459.67+T) =		0.0630	lbm/ft^3	
Dry Air rho IN:	rho a = (144/Ra)*(Pa/(459.67+T) =		0.061575	lbm/ft^3	
Dry Bulb T IN:	T=		148	F	
Outlet Air Flow:	V =		28500	cfm	
Sat Air P:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$		2.47	psia	
Moist Air Rel. Humidity:	RH = Pv/Ps =		18.33%		
Equation Coeff.:	a =		2.358607E-02		
	b =		1.007276E-03		
	c =		1.888033E-05		
	d =		3.775047E-07		
	e =		4.871208E-10		
	f =		2.109071E-11		

Data Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
VY04 @ 104 F, 5% PLUG, MAX FF

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	32,483.00 acfm	82.00 gpm
Inlet Dry Bulb Temp	°F	105.00 °F
Inlet Wet Bulb Temp	°F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.005000
Air-Side Fouling	0.000500
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	19.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% PLUG, MAX FF

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	27.30
Air Flow (acfm)	28,500.00
Tube Inlet Temp (°F)	104.00
Air Inlet Temp (°F)	133.9
Inlet Relative Humidity (%)	18.33
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% PLUG, MAX FF

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	107,826.38	13,563.44	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	133.86	104.00	j Factor	
Outlet Temperature (°F)	122.69	126.25	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	5,453.10
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	301,411
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	301,411
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	107,826.38	13,563.44	Tube-Side hi (BTU/hr·ft^2·°F)	185.54
Inlet Temperature (°F)	133.86	122.79	j Factor	0.0115
Outlet Temperature (°F)	132.86	126.79	Air-Side ho (BTU/hr·ft^2·°F)	20.17
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
Average Temp (°F)	133.36	124.79		
Skin Temperature (°F)	131.07	128.03	U Overall (BTU/hr·ft^2·°F)	4.73
Velocity ***	5,910.87	0.53	Effective Area (ft^2)	681.64
Reynold's Number	1,637	4,018	LMTD	8.40
Prandtl Number	0.7264	3.4618	Total Heat Transferred (BTU/hr)	27,083
Bulk Visc (lbm/ft·hr)	0.0483	1.2879		
Skin Visc (lbm/ft·hr)		1.2506	Surface Effectiveness (Eta)	0.8797
Density (lbm/ft^3)	0.0632	61.6359	Sensible Heat Transferred (BTU/hr)	27,083
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0160	0.3716	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	107,826.38	13,563.44
Inlet Temperature (°F)	132.86	121.68
Outlet Temperature (°F)	131.85	125.70
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	132.35	123.69
Skin Temperature (°F)	130.05	127.00
Velocity ***	5,910.87	0.53
Reynold's Number	1,639	3,977
Prandtl Number	0.7265	3.5001
Bulk Visc (lbm/ft·hr)	0.0483	1.3009
Skin Visc (lbm/ft·hr)		1.2623
Density (lbm/ft^{3})	0.0633	61.6535
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3713

Tube-Side hi (BTU/hr·ft^{2}·°F)	183.32
j Factor	0.0115
Air-Side ho (BTU/hr·ft^{2}·°F)	20.16
Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00024732
Overall Fouling (hr·ft^{2}·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^{2}·°F)	4.71
Effective Area (ft^{2})	681.64
LMTD	8.49
Total Heat Transferred (BTU/hr)	27,242
Surface Effectiveness (Eta)	0.8798
Sensible Heat Transferred (BTU/hr)	27,242
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	107,826.38	13,563.44
Inlet Temperature (°F)	131.85	117.78
Outlet Temperature (°F)	130.59	122.79
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	131.22	120.29
Skin Temperature (°F)	128.36	124.55
Velocity ***	5,910.87	0.53
Reynold's Number	1,641	3,853
Prandtl Number	0.7266	3.6237
Bulk Visc (lbm/ft·hr)	0.0482	1.3428
Skin Visc (lbm/ft·hr)		1.2907
Density (lbm/ft^{3})	0.0634	61.7072
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3701

Tube-Side hi (BTU/hr·ft^{2}·°F)	176.58
j Factor	0.0115
Air-Side ho (BTU/hr·ft^{2}·°F)	20.15
Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00024732
Overall Fouling (hr·ft^{2}·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^{2}·°F)	4.64
Effective Area (ft^{2})	681.64
LMTD	10.73
Total Heat Transferred (BTU/hr)	33,912
Surface Effectiveness (Eta)	0.8798
Sensible Heat Transferred (BTU/hr)	33,912
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^{2}), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	107,826.38	13,563.44
Inlet Temperature (°F)	130.59	116.79
Outlet Temperature (°F)	129.36	121.68
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	129.97	119.24
Skin Temperature (°F)	127.18	123.46
Velocity ***	5,910.87	0.53
Reynold's Number	1,644	3,815
Prandtl Number	0.7267	3.6633
Bulk Visc (lbm/ft·hr)	0.0481	1.3562
Skin Visc (lbm/ft·hr)		1.3037
Density (lbm/ft^3)	0.0635	61.7235
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3698

Tube-Side hi (BTU/hr·ft^2·°F)	174.41
j Factor	0.0115
Air-Side ho (BTU/hr·ft^2·°F)	20.14
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^2·°F)	4.62
Effective Area (ft^2)	681.64
LMTD	10.54
Total Heat Transferred (BTU/hr)	33,160
Surface Effectiveness (Eta)	0.8799
Sensible Heat Transferred (BTU/hr)	33,160
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	107,826.38	13,563.44
Inlet Temperature (°F)	129.36	111.58
Outlet Temperature (°F)	127.80	117.78
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	128.58	114.68
Skin Temperature (°F)	125.03	120.32
Velocity ***	5,910.87	0.53
Reynold's Number	1,647	3,652
Prandtl Number	0.7268	3.8433
Bulk Visc (lbm/ft·hr)	0.0480	1.4168
Skin Visc (lbm/ft·hr)		1.3423
Density (lbm/ft^3)	0.0637	61.7922
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3682

Tube-Side hi (BTU/hr·ft^2·°F)	165.35
j Factor	0.0115
Air-Side ho (BTU/hr·ft^2·°F)	20.12
Tube Wall Resistance (hr·ft^2·°F/BTU)	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^2·°F)	4.52
Effective Area (ft^2)	681.64
LMTD	13.65
Total Heat Transferred (BTU/hr)	42,037
Surface Effectiveness (Eta)	0.8800
Sensible Heat Transferred (BTU/hr)	42,037
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

19:13:36 **PROTO-HX 3.01 by Proto-Power Corporation (SN#663-7371)** 04/23/02

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% PLUG, MAX FF

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	107,826.38	13,563.44
Inlet Temperature (°F)	127.80	110.91
Outlet Temperature (°F)	126.33	116.79
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	127.06	113.85
Skin Temperature (°F)	123.71	119.25
Velocity ***	5,910.87	0.53
Reynold's Number	1,650	3,622
Prandtl Number	0.7269	3.8777
Bulk Visc (lbm/ft·hr)	0.0479	1.4284
Skin Visc (lbm/ft·hr)		1.3560
Density (lbm/ft^3)	0.0639	61.8045
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3679

Tube-Side hi (BTU/hr·ft^2·°F)	163.58
j Factor	0.0114
Air-Side ho (BTU/hr·ft^2·°F)	20.11
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^2·°F)	4.50
Effective Area (ft^2)	681.64
LMTD	12.98
Total Heat Transferred (BTU/hr)	39,788
Surface Effectiveness (Eta)	0.8801
Sensible Heat Transferred (BTU/hr)	39,788
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	107,826.38	13,563.44
Inlet Temperature (°F)	126.33	104.00
Outlet Temperature (°F)	124.42	111.58
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	125.37	107.79
Skin Temperature (°F)	121.05	115.30
Velocity ***	5,910.87	0.53
Reynold's Number	1,654	3,410
Prandtl Number	0.7270	4.1446
Bulk Visc (lbm/ft·hr)	0.0478	1.5176
Skin Visc (lbm/ft·hr)		1.4083
Density (lbm/ft^3)	0.0641	61.8909
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3657

Tube-Side hi (BTU/hr·ft^2·°F)	151.44
j Factor	0.0114
Air-Side ho (BTU/hr·ft^2·°F)	20.09
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.07479374
U Overall (BTU/hr·ft^2·°F)	4.35
Effective Area (ft^2)	681.64
LMTD	17.29
Total Heat Transferred (BTU/hr)	51,316
Surface Effectiveness (Eta)	0.8801
Sensible Heat Transferred (BTU/hr)	51,316
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

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Attachment C
Page No. C13 of C14

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

VY04 @ 104 F, 5% PLUG, MAX FF

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	107,826.38	13,563.44
Inlet Temperature (°F)	124.42	103.99
Outlet Temperature (°F)	122.69	110.91
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	123.55	107.45
Skin Temperature (°F)	119.60	114.35
Velocity ***	5,910.87	0.53
Reynold's Number	1,658	3,398
Prandtl Number	0.7272	4.1603
Bulk Visc (lbm/ft·hr)	0.0477	1.5228
Skin Visc (lbm/ft·hr)		1.4214
Density (lbm/ft³)	0.0643	61.8956
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0158	0.3656

Tube-Side hi (BTU/hr·ft²·°F)	150.61
j Factor	0.0114
Air-Side ho (BTU/hr·ft²·°F)	20.07
Tube Wall Resistance (hr·ft²·°F/BTU)	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.07479374
U Overall (BTU/hr·ft²·°F)	4.34
Effective Area (ft²)	681.64
LMTD	15.84
Total Heat Transferred (BTU/hr)	46,873
Surface Effectiveness (Eta)	0.8802
Sensible Heat Transferred (BTU/hr)	46,873
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

PROTO-POWER CORPORATION
CALCULATION TITLE SHEET

CLIENT: Commonwealth Edison

PROJECT: LaSalle Station GL 89-13 Heat Exchanger Testing Program

CALCULATION TITLE: VY Cooler Thermal Performance Model -- 1(2)VY04A

CALCULATION NO.: 97-198

FILE NO.: 31-003

COMPUTER CODE & VERSION (if applicable): PROTO-HX™, Version 3.01

REV	TOTAL NO. OF PAGES	ORIGINATOR/DATE	VERIFIER/DATE	APPROVAL/DATE
A	240	Lloyd Philpot Philpot 7/13/98	Merid Aboye 7/13/98	Philpot 7/13/98

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	VERIFIED BY M. Aboye		JOB NO. 31-003
CLIENT Commonwealth Edison	PROJECT LaSalle Station GL 89-13 Heat Exchanger Testing		
TITLE VY Cooler Thermal Performance Model -- 1(2)VY04A			

Revision History

Revision	Revision Description
A	Original Issue

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	ORIGINATOR L. Philpot		DATE 7/13/98
	VERIFIED BY M. Aboye		JOB NO. 31-003
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TITLE VY Cooler Thermal Performance Model -- 1(2)VY04A			

CALCULATION VERIFICATION FORM

REVIEW METHOD:

Approach Checked: ☑ N/A ☐
Logic Checked: ☑ N/A ☐
Arithmetic Checked: ☑ N/A ☐
Alternate Method ☐ N/A ☑
(Attach Brief Summary)
Computer Program Used ☐ N/A ☑
(Attach Listing)
Other ☐ N/A ☑

EXTENT OF VERIFICATION:

Complete Calculation: ☑
Revised areas only: ☐
Other (describe below): ☐

*Errors Detected

Minor Editorial

*Error Resolution

Resolved

*Other Comments

*Extra References Used

*(Attach extra sheets if needed)

CALCULATION FOUND TO BE VALID AND CONCLUSIONS TO BE CORRECT AND REASONABLE:

IDV Signature:
Initials: MA

Printed Name: MERID ABOYE
Date: 7-13-98

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TITLE VY Cooler Thermal Performance Model -- 1(2)VY04A			

LIST OF ATTACHMENTS

Attachment	**Subject Matter**	**Total Pages**
A	Attachment A to Proto-Power Calculation 97-198 Rev. A: Design Input Data -- Selected References	11
B	Attachment B to Proto-Power Calculation 97-198 Rev. A: Cooler Inspection Photographs -- 1VY01A and 1VY02A	2
C	Attachment C to Proto-Power Calculation 97-198 Rev. A: PROTO-HX™ Reports -- Initial Benchmark Case	14
D	Attachment D to Proto-Power Calculation 97-198 Rev. A: Excerpt from *Compact Heat Exchangers*, Kays and London	2
E	Attachment E to Proto-Power Calculation 97-198 Rev. A: PROTO-HX™ Reports -- Final Benchmark Case	27
F	Attachment F to Proto-Power Calculation 97-198 Rev. A: PROTO-HX™ Reports -- Thermal Margin Assessment (Clean)	14
G	Attachment G to Proto-Power Calculation 97-198 Rev. A: PROTO-HX™ Reports -- Thermal Margin Assessment (Service)	14
H	Attachment H to Proto-Power Calculation 97-198 Rev. A: Derivation of Moist Air Properties	13
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J	Attachment J to Proto-Power Calculation 97-198 Rev. A: PROTO-HX™ Analytical Uncertainty Analysis	55
K	Attachment K to Proto-Power Calculation 97-198 Rev. A: Comparing Surface Areas of Spiral and Circular Fins	4
L	Attachment L to Proto-Power Calculation 97-198 Rev. A: Walkdown Data for Coil Physical Dimensions	5
M	Attachment M to Proto-Power Calculation 97-198 Rev. A: PROTO-HX™ Reports -- Fouling Sensitivity Analysis	27
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CLIENT Commonwealth Edison	PROJECT LaSalle Station GL 89-13 Heat Exchanger Testing		
TITLE VY Cooler Thermal Performance Model -- 1(2)VY04A			

1. PURPOSE

The purpose of this calculation is to develop a thermal performance analysis model for the Commonwealth Edison (ComEd) LaSalle Station NE cubicle area coolers 1(2)VY04A. This model can be used for the analysis of heat exchanger thermal performance test data as part of the LaSalle Station GL 89-13 heat exchanger testing program or for any other engineering analysis subject to the limitations itemized at the end of this section.

Once developed, the model is used to identify the thermal margin of the heat exchanger at specified performance conditions as follows:

- at LaSalle Station Reference Conditions as currently defined in the LaSalle Station design and licensing basis; and
- at lower service water flow rates (with increased fouling) to support service water system re-balancing efforts.

The thermal performance model documented in this calculation has been created and used with PROTO-HX, Version 3.01. The model can be used with previous versions of PROTO-HX and produce identical results as long as the following restriction is upheld:

- Air coils analyzed in Version 3.0 or earlier can be analyzed only in non-condensing modes of operation.

Current limitations of use for PROTO-HX are established by the limits on fluid properties included within the software. Fluid properties contained within PROTO-HX are currently limited to the following temperature ranges:

- Air: 32-320°F
- Water: 32-500°F

2. BACKGROUND

LaSalle Station is in the process of implementing a heat exchanger thermal performance monitoring program and a service water system flow balancing program in response to the requirements of NRC Generic Letter 89-13. Development of an analytical model in PROTO-HX™, Version 3.01, will allow timely analysis of data resulting from the test program and will ensure the limiting flow requirements for the coolers are adequately defined.

3. DESIGN INPUTS

The thermal performance model is developed using PROTO-HX™, Version 3.01. PROTO-HX™ was developed and validated in accordance with Proto-Power's Nuclear Software Quality Assurance Program (SQAP). This program meets the requirements of 10CFR50 Appendix B, 10CFR21, and ANSI NQA-1, and was developed in accordance with the guidelines and standards contained in ANSI/IEEE Standard 730/1984 and ANSI NQA-2b-1991. PROTO-HX™ Version 3.01 was verified and approved for use as documented in Reference (1).

The design inputs for this calculation consist of the heat exchanger design basis performance requirements (Table1), performance specifications (Table 2) and construction details (Table 3) provided by the heat exchanger manufacturer data sheet (Attachment A) or other design documents as referenced. Construction details give the necessary information for model construction while performance specifications are used to benchmark the model.

VY cooler thermal performance in this calculation will be assessed only with respect to the nominal accident conditions (i.e., design basis LOCA) with no tubes plugged. Condensing modes of operation and tube plugging margins are not addressed.

Since the 1(2)VY04A cooler is made up of two separate and unique coil sections (a 4-row front coil and an 8-row back coil), two separate models will be developed.

Table 1: LaSalle Station Reference Conditions

Parameter	Value	Reference*
Heat Rate (BTU/hr)	633,288	2
Atmospheric Pressure (in-w.g.)	-0.4	4
Air-Side Inlet Temperature -- Dry Bulb (°F)	148	4
Fan Volumetric Flow Rate (cfm)	28,500	18,19
Tube-Side Flow Rate (gpm)	200 (total)	5
Tube-Side Inlet Temperature (°F)	100	6

*Selected references included as Attachment A

Table 2: Vendor Specified Performance

Parameter	**Back Coil**	**Front Coil**	**Reference***
Air-Side Fouling Factor (Design)	0	0	Assumption (1)
Air-Side Entering Fluid Flow Rate (scfm)	27,450	27,450	7
Air-Side Inlet Dry Bulb Temperature (°F)	-	150	7
Air-Side Inlet Wet Bulb Temperature (°F)	-	92	7
Air-Side Outlet Dry Bulb Temperature (°F)	109.0	-	7
Air-Side Outlet Wet Bulb Temperature (°F)	84.0	-	7
Tube Side Fouling Factor (Design)	0.0015	0.0015	8
Tube Side Fluid Type	Service Water (Fresh)	Service Water (Fresh)	9,10
Tube Side Fluid Flow Rate (gpm)	Note (1)	Note (1)	-
Tube Side Inlet Temperature (°F)	105	105	7
Tube Side Outlet Temperature (°F)	Note (2)	Note (2)	-
Design Q (BTU/hr)	Note (3)	Note (3)	-

Notes:

(1) A combined flow of 200 gpm is reported on the vendor data sheet (Reference (7))
(2) A combined outlet temperature of 117.31°F is reported on the vendor data sheet (Reference (7))
(3) A combined heat load of 1,194,000 BTU/hr is reported on the vendor data sheet (Reference (7))

*Selected references included as Attachment A

Table 3: Construction Details

Parameter	**Back Coil**	**Front Coil**	**Reference(1)**
Heat Exchanger Type and relative direction of Tube-side and Air flow .	Carrier Air Coil Counter flow	Carrier Air Coil Counter flow	7,11
Fin Type	Spiral	Spiral	7,8
Coil Finned Length (in)	108.00 - specified (2) 105.00 - effective (2)	108.00 - specified (2) 105.00 - effective (2)	7 20
Fin Pitch (fins/in)	10.0	10.0	7
Fin Material	ASTM B209 Al.	ASTM B209 Al.	7
Fin Conductivity (BTU/hr-ft-°F)	128	128	16
Fin Thickness (in)	0.012	0.012	7
Fin Height (in)	1.347	1.347	20
Number of Coils per Unit	2	2	7
Number of Tube Rows	8	4	7
Number of Tubes per Row	20	20	7
Number of Plugged Tubes	0	0	-
Tube Outside Diameter (in)	0.625 (3)	0.625 (3)	7
Tube Wall Thickness (in)	0.049	0.049	7
Tube Inside Diameter (in)	0.527	0.527	7
Longitudinal (horiz.) Tube Pitch (in)	see Section 6	see Section 6	-
Transverse (vertical) Tube Pitch (in)	1.370	1.370	20
Tube Layout	Staggered	Staggered	20
Number of Serpentines	2 (i.e., Double Circuiting)	2 (i.e., Double Circuiting)	7
Tube Wall Material	SB75 Copper	SB75 Copper	7
Tube Wall Conductivity (BTU/hr-ft-°F)	225	225	12
Sensible Heat Ratio	1	1	(Section 6.3)

Notes: (1) Selected references included as Attachment A

(2) The Reference 7 coil finned length will be used for benchmarking to vendor performance data per Section 6.0. The Reference 20 effective coil finned length will be used for subsequent analyses.

(3) The Reference 7 tube OD is within the tolerance of Reference 20 and will be used in lieu of Ref. 20.

4. APPROACH

This calculation utilizes plant/vendor fabrication specifications provided in Section 3.0 to develop a thermal performance prediction model for the 1(2)VY04A coolers. The calculation then benchmarks the model by comparing the heat transfer rate calculated by PROTO-HX™ Version 3.01 with the manufacturer's specifications for thermal performance. The Colburn j-factor vs. Reynolds Number relationship is adjusted as necessary to meet the manufacturer's performance specifications. After the model is benchmarked, it will be used to determine the margin between the available and required heat removal rates and to establish a revised limiting flow rate in support of service water system re-balancing efforts.

5. ASSUMPTIONS

1. The fouling factor specified in Reference (8) is for the tube-side only and design air-side fouling is zero. This is typical for air coils of this type and application. Future validation of this assumption is not required.

2. The vendor-supplied performance specifications of Reference (7) (included as Attachment A) are considered to be an accurate reflection of the as-built performance of the VY Cooler. Future validation of this assumption is not required.

3. The slope of the "Colburn j-factor vs. Reynolds Number" curve is the same for the current coil and the standard coil represented by curve "CF-9.05-3/4 J-A" in the PROTO-HX™ "h-configurations" Library. This assumption is based on physical similarities between the VY coolers and the standard configuration represented by "CF-9.05-3/4 J-A" as elaborated in Section 6, below. The model benchmarking process described in Section 6 brings the model into precise agreement with the vendor performance data making initial configuration selection immaterial. The only difference caused by initial configuration selection that would be detectable in analysis results is when analyses are performed over a very wide range (orders of magnitude) of air-side Reynolds numbers. A wide range of Reynolds numbers causes the slight variation in slopes of the j-factor equations of different configurations to become more obvious. Given the fixed fan flow rate and a relatively tight band of normal operating and Reference conditions, along with the fact that benchmarking conditions are extremely close to Reference conditions, such wide variations in Reynolds numbers are not anticipated. Future validation of this assumption is not required.

4. The portion of the total flow that is directed toward the front coil section will equally divide between the top and bottom coils since these coils are identical with no tubes

plugged. The portion of the total flow that is directed toward the back coil section will equally divide between the top and bottom coils since these coils are identical with no tubes plugged. Future validation of this assumption is not required.

5. The front and back coil sections have the same Colburn j-factor vs. Reynolds Number relationship. This assumption is based on physical similarities between the VY coolers and the standard configuration represented by "CF-9.05-3/4 J-A" as elaborated in Assumption 3 above and Section 6, below. Future validation of this assumption is not required.

6. The VY cooler spiral fin geometry is closely approximated by the PROTO-HX™ circular fin configuration. This is due to the relatively tight fin pitch configuration resulting in a negligible difference in fin/tube outside surface area. This assumption is supported in Attachment K. Future validation of this assumption is not required.

7. In transitioning from the original vendor specified inlet air temperature of 150°F to the current licensing limit of 148°F, the inlet air vapor density is assumed to have remained unchanged. This increases the inlet relative humidity causing a slight reduction in the air mass flow rate. Future validation of this assumption is not required.

6. ANALYSIS

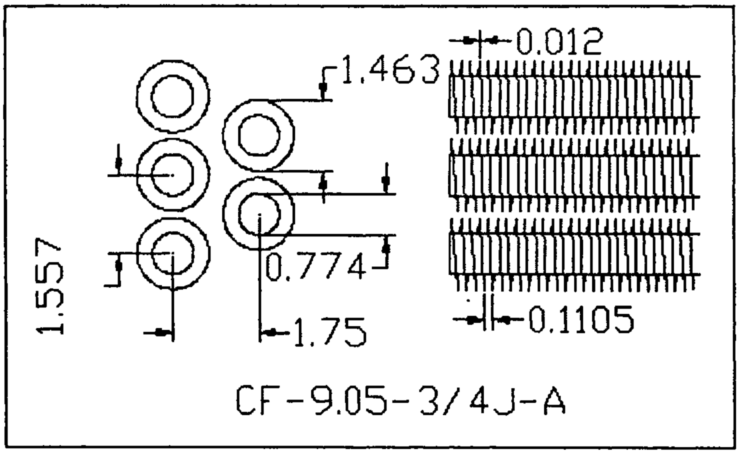
6.1 Tube Pitch

The transverse and longitudinal tube pitches are not directly available from the coil data sheet. They can be estimated based on the geometry of the coil. Per Reference (7), the coil stack depth is 8.00 inches for the front coil and 12.00 inches for the back coil. Dividing the stack depth evenly between 4 and 8 tube rows yields a longitudinal (horizontal) tube pitch of 2.00 and 1.500 inches for the front and back coils respectively.

6.2 Coil Configuration

The coil configuration for modeling coolers 1(2)VY04A is selected based on the physical characteristics of the coil. There are no coils in the PROTO-HX™ library that exactly match the configuration of the VY coolers. The configuration "CF-9.05-3/4 J-A" shown in Figure 1 provides the closest match based on similarities of layout geometry: staggered tube rows, horizontal tube pitch slightly greater than vertical tube pitch, similar fin height, identical fin thickness and similar fin pitch. The "CF-9.05-3/4 J-A" configuration also represents a relatively compact coil which correlates well to the VY coils as evidenced in the coil photographs included as Attachment B.

Figure 1 Coil Configuration CF-9.05-3/4 J-A



PROTO-HX™ does not include spiral fin configurations in the analytical methodology employed. However, for the given fin pitch, the difference in calculated fin surface area and outside heat transfer film coefficient between the VY cooler spiral fin configuration and the PROTO-HX™ circular fin configuration is negligible. The negligible difference is illustrated further in Attachment K using a simplified area comparison.

6.3 Sensible Heat Ratio

The value input in the model for the Sensible Heat Ratio (SHR) is used only when one of the "Constant Heat Load" calculation/extrapolation methods of PROTO-HX™ is used (i.e., "Constant Heat and Cold Inlet Temperature" or "Constant Heat and Hot Outlet Temperature"). The SHR can be assigned any value between 0 and 1 and represents the fraction of the total specified (constant) heat load that is due to sensible cooling alone. An input of 1.0 in the SHR field tells PROTO-HX™ that the specified constant heat is 100% sensible heat with no condensation occurring. Use of any value less than 1.0 presumes some knowledge as to what fraction of the specified heat load is due to condensation (i.e., latent heat transfer). The value of SHR currently in the model is 1.0, but like any other model input, the SHR can be changed at any time.

6.4 Derivation of Benchmarking Inputs -- Front Coil

The PROTO-HX™ model is benchmarked using the performance data provided by the cooler manufacturer. In order to benchmark the model, the vendor specified conditions must be converted into appropriate units for PROTO-HX™ input. The only input requiring adjustment is the specified air-side flow rate of 27,450 *scfm*. PROTO-HX™ requires air-side flow rate to be given at actual inlet air conditions (units of *acfm*).

The correction of *scfm* to *acfm* is made as follows (holding mass flow rate constant for the defining case):

$$\dot{m} = (\text{scfm}) \text{ x } (\rho_{\text{std}}) \text{ x } \left(\frac{60\,\text{min}}{1\,\text{hr}}\right) = (\text{acfm}) \text{ x } (\rho_{\text{actual}}) \text{ x } \left(\frac{60\,\text{min}}{1\,\text{hr}}\right) \qquad \text{Equation (1)}$$

where:

$\dot{m}$ = mass flow (lbm/hr)

scfm = volumetric flow rate at standard conditions (ft^3/min)

ρ_{std} = standard density of 0.075 lbm/ft^3

acfm = volumetric flow rate at specified (non-standard) conditions (ft^3/min)

ρ_{actual} = density of dry air at specified inlet temperature and humidity (lbm/ft^3)

Rearranging terms yields the following correction factor for converting scfm to inlet acfm:

$$(\text{acfm}) = (\text{scfm}) \text{ x } \frac{(\rho_{\text{std}})}{(\rho_{\text{actual}})} \qquad \text{Equation (2)}$$

Local Standard Atmospheric Pressure

To derive the dry air density for the inlet air conditions, the amount of moisture in the air and the local atmospheric pressure must be accounted for. Per Reference (13), local atmospheric pressure was accounted for by specifying a flow at standard density (27,450 scfm) as well as an actual flow (28,500 acfm at 70°F and 40% relative humidity at site elevation). The difference between the two flow rates will provide the assumed air density as follows:

$$(\rho_{\text{actual}}) = (\text{scfm}) \times \frac{(\rho_{\text{std}})}{(\text{acfm})} = (27{,}450) \times \frac{0.07500}{28{,}500} = 0.0722 \ \text{lbm}/\text{ft}^3$$

The local atmospheric pressure is found by iterative solution using Reference (14) as shown in Attachment H. Pressure input is varied with the specified temperature and humidity conditions held constant until a dry air density of 0.0722 lbm/ft^3 is reached. The result of the iterative process is as follows:

Given per Reference (13)
Dry Bulb Temperature: 70.00°F
Relative Humidity: 40.00 %

Derived above
Dry Air Density: 0.0722 lbm/ft^3

Derived per Attachment H
Specific Humidity: 0.00638 lbmv/lbma
Atmospheric Pressure: **14.3150 psia**
Dry Air Pressure: 14.1697 psia
Vapor Pressure: 0.1453 psia
Vapor Density: 0.00046 lbm/ft^3

The result is that an atmospheric pressure of 14.315 psia at 70°F and 40% relative humidity will give the requisite air density.

Actual Air-Side Flow Rate

The next step is to define the actual air flow rate at the inlet conditions included by the vendor in the Reference (7) performance specification (Table 2). The moist air conditions corresponding to the vendor specified performance conditions are as follows:

Given per Reference (7)
Dry Bulb Temperature: 150.00°F
Wet Bulb Temperature: 92.00°F

Derived above

Atmospheric Pressure:	14.315 psia

Derived per Attachment H

Relative Humidity:	12.18 %
Specific Humidity:	0.02034 lbmv/lbma
Dry Air Pressure:	13.8617 psia
Vapor Pressure:	0.4533 psia
Dry Air Density:	**0.06137 lbm/ft^3**
Vapor Density:	0.001248 lbm/ft^3

The actual volumetric flow rate at vendor specified inlet conditions is then calculated as:

$$(\text{acfm}) = (\text{scfm}) \text{ x } \frac{(\rho_{\text{std}})}{(\rho_{\text{actual}})} = (27{,}450) \text{ x } \frac{0.07500}{0.06137} = 33{,}546 \ {}^{\text{ft}^3}\!/_{\text{min}}$$

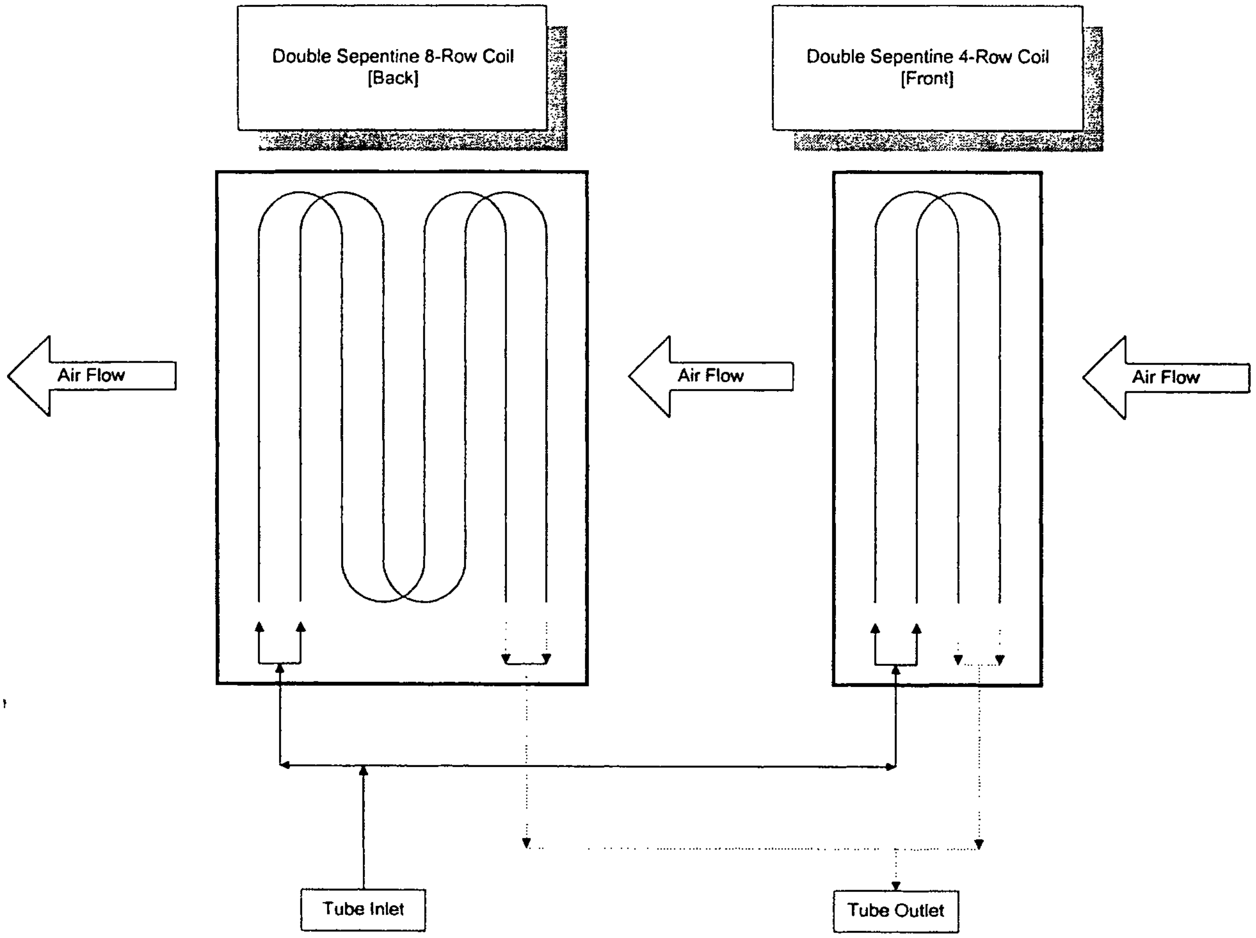
Actual Tube-Side Flow Rate

In accordance with Reference (7), both the front and back coil sections are double circuited (double serpentine) coils with 20 tubes per row. A plan view of this configuration is shown in Figure 2. Both the front and back coil sections have an equal number of open tube circuits available to the incoming flow. The flow split between the coil sections, therefore, will be a function of the flow resistance of each coil with the majority of the flow going to the coil section that offers the least resistance to flow. By inspection, the majority of the incoming flow will go to the front coil due to the shorter length of tube and fewer tube bends. A quantitative derivation of the flow split is possible by accounting for the sources of flow resistance in each flow path.

Given that the top and bottom and front and back coil sections are located in parallel, the total flow to the VY04A cooler splits four ways as follows:

$$Q_{\text{total}} = Q_{\text{front-top}} + Q_{\text{front-bottom}} + Q_{\text{back-top}} + Q_{\text{back-bottom}} \qquad \text{Equation (3)}$$

Figure 2 Top View of Back and Front Coil Sections (Double Serpentine Tube Arrangement)



As given on page 3-4 of Reference (3), the relation between head loss (or differential pressure) across a flow path and flow is given as:

$$\Delta P \propto KQ^2$$

Equation (4)

where:

ΔP = differential pressure

K = resistance coefficient

Q = flow

Given that the differential pressure across the coil sections will be the same and the symmetry of the tube flow paths between all coil sections (i.e., the same number of tube circuits in each coil section), the analysis of flow resistance reduces to a comparison of a single tube circuit in a front coil section to a single tube circuit in a back coil section.

$$\Delta P \propto K_F Q_F^2 = K_B Q_B^2 \qquad \text{Equation (5)}$$

where:

K_F = front coil resistance coefficient
Q_F = front coil flow
K_B = back coil resistance coefficient
Q_B = back coil flow

The resistance coefficient is a combination of straight tube length and tube bends as shown in Figure 2. The resistance coefficient for each tube can be expressed as:

$$K_{tube} = K_{straight\ tube} + K_{bend} \qquad \text{Equation (6)}$$

where:

$K_{straight\ tube}$ = straight length resistance [= f x (L/D)], Reference (3), page 3-4

K_{bend} = close pattern return bend [= 50 x f], Reference (3), page A-29

Comparing the front and back coil sections in terms of straight length and bends for each tube gives the following per Figure 2:

Front Coil Tube: 2 straight lengths and 1 bend

Back Coil Tube: 4 straight lengths and 3 bends

Expressing the front and back coil tube resistances in terms of Equation (6) gives the following:

$$K_F = (2 \times K_{straight\ tube}) + (1 \times K_{bend}) = (2 \times f \times (L/D)) + (1 \times 50 \times f) = f(2L/D + 50) \qquad \text{Eq. (7)}$$

$$K_B = (4 \times K_{straight\ tube}) + (3 \times K_{bend}) = (4 \times f \times (L/D)) + (3 \times 50 \times f) = f(4L/D + 150) \qquad \text{Eq. (8)}$$

Substituting into Equation (5) and canceling like terms:

$$K_F Q_F^2 = K_B Q_B^2 \qquad \text{Equation (9)}$$

$$(2L/D + 50)Q_F^2 = (4L/D + 150)Q_B^2 \qquad \text{Equation (10)}$$

Given a straight tube length of 108 inches and a tube inside diameter of 0.527 inches yields the following after substituting and rearranging terms:

$$\frac{Q_B}{Q_F} = \left[\frac{\left((2)\text{x}\dfrac{(108)}{(0.527)}\right)+(50)}{\left((4)\text{x}\dfrac{(108)}{(0.527)}\right)+(150)}\right]^{\frac{1}{2}} = \left[\frac{459.87}{969.73}\right]^{\frac{1}{2}} = 0.69 \qquad \text{Equation (11)}$$

To express the flow split as a function of the total flow, the ratio derived above is substituted into Equation (3) as follows (recognizing the symmetry of top and bottom coil sections):

$$Q_{total} = Q_{front\text{-}top} + Q_{front\text{-}bottom} + Q_{back\text{-}top} + Q_{back\text{-}bottom} = Q_F + Q_B \qquad \text{Equation (12)}$$

$$\frac{Q_{total}}{Q_F} = \frac{Q_F}{Q_F} + \frac{Q_B}{Q_F} = 1 + (0.69) = 1.69 \qquad \text{Equation (13)}$$

$$\frac{Q_F}{Q_{total}} = \frac{1}{1.69} = 0.59 \qquad \text{Equation (14)}$$

$$\frac{Q_B}{Q_{total}} = 1 - \frac{Q_F}{Q_{total}} = 1 - 0.59 = 0.41 \qquad \text{Equation (15)}$$

For the case where the cooler is supplied with 200 gpm, the flow split between the front and back coil sections will be:

Front Coil Flow = (200 gpm) x (0.59) = 118 gpm

Back Coil Flow = (200 gpm) x (0.41) = 82 gpm

Summary of PROTO-HX™ Inputs for Model Benchmarking

Front Coil:

Tube-Side Flow Rate	118 gpm
Tube-Side Inlet Temperature	105°F
Air-Side Flow Rate	33,546 acfm
Air-Side Inlet Temperature -- Dry Bulb	150°F
Air-Side Inlet Temperature -- Wet Bulb	92°F
Atmospheric Pressure	14.315 psia

Back Coil:

Tube-Side Flow Rate	82 gpm
Tube-Side Inlet Temperature	105°F
Air-Side Flow Rate	(Function of front coil performance)
Air-Side Inlet Temperature -- Dry Bulb	(Function of front coil performance)
Air-Side Inlet Temperature -- Wet Bulb	(Function of front coil performance)
Atmospheric Pressure	14.315 psia

6.5 Model Benchmarking

Benchmarking Process

Model benchmarking is performed to compare thermal performance as predicted by the model to thermal performance specified by the cooler vendor. A significant impact on the model predicted performance is the outside (air-side) heat transfer coefficient. The benchmarking process adjusts the model correlation for outside heat transfer coefficient to match vendor performance data.

An extensive source of information pertaining to the outside heat transfer coefficient for air coolers is provided by Reference (15). This widely-recognized publication provides heat transfer correlations for specific coil configurations. The format used in Reference (15), and subsequently adopted by other researchers, is to provide a plot of the Colburn j-factor vs. Reynolds Number for each configuration.

Alternatively, to permit modeling of coils which do not adequately fit the library configurations and for which no test data correlation is available, PROTO-HX™ allows the generation of a coil unique formulation for outside heat transfer coefficient. This is done through establishing a unique Colburn j-factor for the coil.

Reference (15) defines the Colburn j-factor as follows.

Let:

$c_{pa} =$	Specific heat of air (Btu/lb$_m$-°F)
$k_a =$	Thermal conductivity of air (Btu/hr-ft-°F)
$m_a =$	Absolute viscosity of air (lb$_m$/ft-hr)
$r_a =$	Density of air (lb$_m$/ft^3)
$A_{min} =$	Minimum air-side flow area (in^2)
$A_I =$	Frontal Area (in^2)
$D_H =$	Hydraulic diameter (ft)
$d_o =$	Tube outside diameter (in)
$j =$	Colburn j-Factor
$N_C =$	Number of coils per unit
$N_L =$	Number of active tube rows
$Q_a =$	Specified air flow rate (acfm)
$S_L =$	Longitudinal Tube Pitch (in)
$S_T =$	Transverse Tube Pitch (in)

The Prandtl Number for air, Pr_a (a dimensionless parameter), is given by:

$$Pr_a = \frac{c_{pa} \quad \mu_a}{k_a} \qquad \text{Equation (16)}$$

The mass flow rate of air per coil, M_a (lb$_m$/hr), is calculated based on the input total air flow and the number of coils per unit:

$$M_a = \frac{60 \rho_a Q_a}{N_C} \qquad \text{Equation (17)}$$

The bulk-stream mass flux, G (lb$_m$ / hr-ft^2), is:

$$G = \frac{144 M_a}{A_{MIN}} \qquad \text{Equation (18)}$$

The Colburn j-factor is defined in terms of the Stanton Number, St_a, as:

$$j = St_a \ Pr_a^{2/3} = \left(\frac{h_o}{G \ c_{pa}} \right) Pr_a^{2/3} \qquad \text{Equation (19)}$$

Therefore, the outside heat transfer coefficient, h_o (Btu/hr-ft^2-°F), may be defined in terms of the j-factor:

$$h_o = \frac{j \ G \ c_{pa}}{Pr_a^{2/3}} \qquad \text{Equation (20)}$$

Per Reference (15), the j-factor for the various coil configurations tested are provided as functions of the Reynolds Number based on hydraulic diameter, D_H(in):

$$j = f(Re_a) \qquad where: \ Re_a = \frac{G \ D_H}{\mu_a} \qquad \text{Equation (21)}$$

The standard air-side configuration for coil type CF-9.05-3/4 J-A, provided in PROTO-HX™ 's Library, was initially selected based on the physical similarities between the present coil and that represented by CF-9.05-3/4 J-A as described in Section 6.2. However, the heat transfer rate under design operating conditions using the standard configuration was significantly lower than the value specified by the manufacturer (see performance run in Attachment C). For this reason, a new curve relating the Colburn j-factor and Reynolds Number was generated according to the following procedure:

- The slope of the linear standard curve was calculated.
- A new curve, parallel to the standard curve, was defined such that the new j-intercept is slightly lower.
- A design performance run was then executed using the new Colburn j-factor versus Reynolds Number curve, and the resulting heat transfer rate was compared to the manufacturer's value.
- The above two steps were repeated until the calculated heat transfer rate closely matched the manufacturer's value.

Front and Back Coil Considerations

The unique configuration of 1(2)VY04 coolers with front and back coils in parallel for cooling water flow and in series for air flow creates a benchmarking challenge in three ways:

- The cooling water flow split is derived analytically as demonstrated above and, due to the lack of flow measurement capability, cannot be verified.
- The vendor specified performance data does not distinguish between front and back coil sections with regard to total heat transferred by the coil combination or the predicted cooling water outlet temperatures (i.e., what fraction of the total heat load is carried by each coil section).
- The vendor specified performance data does not include air-side inlet conditions for the back coil. Inlet conditions for the back coil section must be derived based on the performance of the front coil section.

The result of the unique challenges of the 1(2)VY04 cooler configuration is that the model benchmarking process becomes iterative in nature and must rely on an assumption of similarity of front and back coil section j-factor corrections [Assumption (5)]. Accordingly, the benchmarking method discussed previously will entail the following additional considerations:

- The front coil section is run with the standard Colburn j-factor.

- Outlet conditions of the front coil section run are used to derive back coil section inlet conditions (i.e., back coil inlet relative humidity is based on front coil outlet temperature and a constant specific humidity across the front coil while back coil inlet air flow is adjusted as necessary to achieve the same mass flow rate as the front coil).

- The back coil section is run with the standard Colburn j-factor.

- The combined heat transfer and cooling water outlet temperature are compared to that specified by the vendor.

- Adjustments to both the front and back coil section are made and the process is repeated (the same Colburn j-factor adjustment made to both front and back coil sections).

- The process is repeated until a combined total heat transfer rate close to the specified heat transfer rate is achieved in conjunction with a combined cooling water outlet temperature close to the specified temperature.

The resulting relationship between Reynolds Number and Colburn j-Factor is represented by the following table and associated equation:

Table 4: Reynolds Number and Colburn j-Factor

Reynolds Number	Colburn j-Factor (Standard)	Colburn j-Factor (Custom)
1000	0.009	0.01360
8000	0.0044	0.00665

$$j = e^{\left[-1.9210 - 0.3441 * \mathrm{Ln}(\mathrm{Re})\right]}$$ Equation (22)

Equation (9) was added to the PROTO-HX™ Library for use in conjunction with Area Coolers 1(2)VY04A.

As noted in Assumption (3) and implemented above, the slope of the "Colburn j-factor vs. Reynolds Number" curve is assumed to be the same for the VY coolers and the standard coil represented by curve CF-9.05-3/4 J-A in the PROTO-HX™ "h-configurations" Library. This assumption is considered reasonable based on the following:

- there are only minor variations in the slope of different j-factor correlations; and,

- there is only a slight variation in the air-side Reynolds Number between anticipated test conditions and the extrapolated accident conditions. The only variation is expected to be caused by air inlet temperature variations (i.e., volumetric flow rate in cfm will be nearly constant, while air flow in acfm will vary with temperature and inlet humidity).

An excerpt from Reference (15), illustrating the Colburn j-factor relationship with Reynolds number, is included as Attachment D.

6.6 Derivation of Back Coil Benchmarking Inputs

The inlet relative humidity and dry air density for the inlet to the back coil section are derived based on the outlet temperature and specific humidity of the front coil section. The equations of Reference (14) are used with the results included in Attachment H.

The inlet air flow rate (acfm) to the back coil is iterated with subsequent runs of the back coil model until a value is reached that maintains constant mass flow rate through both coil sections.

6.7 Effective Coil Finned Length

Reference (20) identified the fact that the finned coil length exposed to air flow was less than that specified by the coil vendor in Reference (7). Model benchmarking used the vendor specified length to be consistent with the vendor specified performance. The effective length is entered into the model for all subsequent analysis. An effective coil finned length of 105.00 inches is used per Reference (20).

6.8 Extrapolation Conditions

The LaSalle Station Reference Conditions defined in Table 1 are slightly different than the vendor specified performance conditions listed in Table 2 and require conversion to units for input into PROTO-HX™.

Air-Side Pressure

Air-side pressure should account for the local elevation above sea level. Chapter 26, Table 1A, of Reference (16) provides elevation and standard atmospheric pressure data for the local area around La Salle.

Interpolating between data points to derive the pressure associated with the elevation of the VY coolers given by Reference (17) provides the following:

Elevation **(feet above sea level)**	**Pressure** **(psia)**	
682	14.337	Reference (16)
738	14.308	Reference (16)
698	14.329	Interpolation between above points at VY elevation

Per Reference (4), the coil pressure is -0.4 inches of water gauge. Using the density of water at 60°F, the specified pressure is calculated as illustrated below:

Coil Pressure (inwg)	**Water Density (lbm/ft$^{3)}$**	**Coil Pressure (psig)**	**Atm Pressure (psia)**	**Coil Pressure (psia)**
-0.4	62.36445	-0.014	14.329	14.315

This pressure matches the pressure derived from the original coil specification in Section 6.4.

Air-Side Flow Rate

In order for PROTO-HX™ to calculate the air mass flow rate for a given extrapolation condition, the inlet dry bulb temperature, total pressure, and relative humidity or wet bulb temperature must be specified. The inlet dry bulb temperature and pressure for the LaSalle Station Reference Conditions are listed in Table 1. The inlet relative humidity is adjusted by holding the vapor density constant from the vendor specified condition to the LaSalle Station Reference Condition (i.e., 148°F in lieu of 150°F).

Given per Section 6.4
Vapor Density: 0.001248 lbm/ft^3

Reference Condition
Dry Bulb Temperature: 148.00°F
Atmospheric Pressure: 14.315 psia

Derived per Attachment H
Wet Bulb Temperature: 91.6°F
Relative Humidity: **12.76 %**

Since fans are constant volume equipment, the air volumetric flow rate of 28,500 cfm specified in References (18) and (19) remains the same for all coil outlet conditions. The air mass flow rate through the coil, however, will vary with the temperature of the air going through the fan (i.e., at coil outlet temperature). Deriving the inlet air flow rate for input to PROTO-HX™ requires an iterative solution as follows:

- take an initial guess at the coil outlet air temperature at the same specific humidity as the coil inlet;
- calculate the dry air density at the selected coil outlet air temperature;
- calculate the coil inlet air flow rate by multiplying the fan capacity (cfm) by the ratio of the coil outlet dry air density to the coil inlet dry air density (to maintain constant mass flow across the coil) [Equation (2)];
- run the model with the inlet air flow rate derived above;
- check the predicted coil outlet air temperature; and
- repeat the process (substituting the predicted coil outlet air temperature for the initial guess) until the coil outlet air temperature does not change from one iteration to the next

The iteration process described above was completed twice for this model for a clean (f = 0.0) and service (f = design) condition with results as follows:

Clean:

$$(\mathrm{cfm}_{\mathrm{in}}) = (\mathrm{cfm}_{\mathrm{out}}) \times \frac{(\rho_{\mathrm{out}})}{(\rho_{\mathrm{in}})} = (28{,}500) \times \frac{(0.066368695)}{(0.061575103)} = 30{,}718.00 \text{ (Fan Temperature = 104.11)}$$

Service:

$$(\mathrm{cfm}_{\mathrm{in}}) = (\mathrm{cfm}_{\mathrm{out}}) \times \frac{(\rho_{\mathrm{out}})}{(\rho_{\mathrm{in}})} = (28{,}500) \times \frac{(0.066134085)}{(0.061575103)} = 30{,}610.12 \text{ (Fan Temperature = 106.11)}$$

Summary of PROTO-HX™ Inputs for Extrapolation to Reference Conditions

The Extrapolation conditions are defined as the vendor data sheet conditions without high energy line break modified for ultimate heat sink temperature and room limiting temperature per the LaSalle Station UFSAR Reference (4).

The required PROTO-HX™ inputs for these conditions are as follows:

Extrapolation -- Front Coil

Tube-Side Flow Rate	118 gpm
Tube-Side Inlet Temperature	100°F
Air-Side Flow Rate	(varies with temperature)
Air-Side Inlet Temperature -- Dry Bulb	148°F
Air-Side Inlet Humidity	12.76%
Atmospheric Pressure	14.315 psia

Extrapolation -- Back Coil

Tube-Side Flow Rate	82 gpm
Tube-Side Inlet Temperature	100°F

It should be noted that the front coil inlet air flow is dependent upon the air temperature exiting the back coil while the back coil inlet air conditions are dependent upon the front coil outlet air conditions. Inlet air flow is calculated from Equation (1) initial estimates of back coil outlet temperature (fan temperature). The back coil inlet air flow rate is derived to ensure the air mass flow rate through the back coil is the same as the air mass flow rate through front coil. The resulting back coil outlet temperature is then compared to the initial estimate. An iterative process is used to ensure all flows are balanced accordingly. Derivation of the necessary air properties is included in Attachment H.

6.9 Thermal Margin Assessment

The available thermal margin is defined as the difference between the available and the required heat removal rates at reference conditions. The maximum available heat removal rate (q_{clean})is calculated using the benchmarked PROTO-HX™ model and the inlet conditions defined in Section 6.8 with zero fouling. By comparing the available heat removal rate calculated with zero fouling to the required heat removal rate, the maximum available margin is determined. A similar comparison is made between the required heat load to the available heat load at design fouling conditions ($q_{service}$).

For the purposes of this thermal margin assessment, thermal margin is defined as follows:

$$\text{Margin (BTU / hr)} = q_{\text{available}} - q_{\text{required}} \qquad \text{Equation (23)}$$

$$\text{Margin (\%)} = \left(\frac{q_{\text{available}} - q_{\text{required}}}{q_{\text{required}}} \right) \text{x } 100 \qquad \text{Equation (24)}$$

where:

$q_{\text{available}}$ = the predicted heat capacity of the cooler at the specified conditions (BTU/hr)

q_{required} = the heat capacity required of the cooler to fulfill design basis requirements (BTU/hr)

6.10 Limiting Cooling Water Flow Analysis

In support of the LaSalle Station efforts to re-balance the CSCS Equipment Cooling Water System, specification of a minimum acceptable cooling water flow to the VY coolers is desired. For conservatism, the design fouling factors associated with the limiting flow analysis are increased to 0.002 on both the tube and air sides of the cooler. Increasing the design fouling factors increases the fouling margin of the cooler at the reduced flow rates.

Limiting flows are established by iterating with the performance model. The cooling water flow rate is incrementally reduced with each iteration until the target thermal margin is achieved. For the case of 1(2)VY04A, the target thermal margin is approximately 30% with the increased design fouling factors.

6.11 Fouling Sensitivity Analysis

To assess the sensitivity of the 1(2)VY04A coolers to tube-side fouling accumulations, a series of iterations are performed. With each iteration, the design tube-side fouling factor is incrementally increased from a value of 0.0000 to 0.0040. The heat removal capability resulting from each fouling increment is compared to the required heat load to assess the thermal margin. Thermal margin is calculated using Equations (10) and (11).

7. RESULTS

7.1 Model Benchmarking

The first model case was based on the standard CF-9.05-3/4 J-A configuration available from the PROTO-HX™ library. The results of this initial benchmarking case are presented in Table 5. The PROTO-HX™ reports associated with the initial benchmark case are included as Attachment C.

Table 5: Initial Benchmark Case -- Standard CF-9.05-3/4 J-A Configuration

Coil	Tube Outlet Temperature (°F)		Heat Transfer Rate (BTU/hr)	
	Vendor Data	P-HX Predicted	Vendor Data	P-HX Predicted
Front	Not specified	116.13	Not specified	651,158
Back	Not specified	116.61	Not specified	471,786
Total	117.31	116.25	1,194,000	1,122,944
Design Variance	--	- 0.90%	--	- 5.95%

(1) Combined outlet temperature is the flow weighted average of the front and back coil sections (front coil = 0.59 and back coil = 0.41 per Equations (14) and (15)).

Based on the results of the initial benchmark case with the standard CF-9.05-3/4 J-A configuration, another case was completed using a customized Colburn J-Factor. This case demonstrated adequate benchmarking of the model to the vendor specified performance. A subsequent comparison run was made following the adjustment of the coil finned length to match the length identified in Reference 20. The results of the final benchmarking cases are presented in Tables 6 and 7. The PROTO-HX™ reports associated with the final benchmarking cases are included as Attachment E.

Table 6: Final Benchmark Case -- Customized Colburn J-Factor

Coil	Tube Outlet Temperature (°F)		Heat Transfer Rate (BTU/hr)	
	Vendor Data	P-HX Predicted	Vendor Data	P-HX Predicted
Front	Not specified	117.75	Not specified	748,549
Back	Not specified	115.94	Not specified	445,586
Total	117.31	117.01	1,194,000	1,194,135
Design Variance	--	- 0.26%	--	+ 0.011%

(1) Combined outlet temperature is the flow weighted average of the front and back coil sections (front coil = 0.59 and back coil = 0.41 per Equations (14) and (15)).

Table 7: Final Benchmark Case -- Effective Finned Tube Length

	Tube Outlet Temperature (°F)		Heat Transfer Rate (BTU/hr)	
Coil	**Vendor Data**	**P-HX Predicted**	**Vendor Data**	**P-HX Predicted**
Front	Not specified	117.62	Not specified	740,828
Back	Not specified	116.01	Not specified	447,161
Total	117.31	116.96	1,194,000	1,187,989
Design Variance	--	- 0.30%	--	- 0.50%

(1) Combined outlet temperature is the flow weighted average of the front and back coil sections (front coil = 0.59 and back coil = 0.41 per Equations (14) and (15)).

7.2 Thermal Margin Analysis

Prior to defining margin, the predicted heat transfer capacity of the cooler ($q_{available}$) is defined. The predicted heat transfer capacities at LaSalle Station Reference Conditions for both clean (zero fouling) and service (design fouling) conditions are summarized in Table 8.

Table 8: Heat Transfer Capacity

Conditions	Coil Heat Transfer Capacity (BTU/hr)	Total Heat Transfer Capacity (BTU/hr)
Clean (f = 0)	(front) 854,494 (back) 391,980	1,246,474
Service (f = 0.0015)	(front) 752,589 (back) 432,781	1,185,370

The thermal margin assessment relates the predicted capacity of the cooler on clean and service conditions to the required capacity under reference conditions. The comparison is provided in Table 9. The PROTO-HX™ reports associated with the thermal margin assessment are included as Attachments F and G for zero and design fouling conditions, respectively.

Table 9: Thermal Margin at LaSalle Station Reference Conditions -- 1(2)VY04A

Conditions	$q_{required}$ (BTU/hr)	$q_{available}$ (BTU/hr)	Margin (BTU/hr)	Margin (%)
Clean (f = 0)	633,288	1,246,474	613,186	96.83%
Service (f = 0.0015)	633,288	1,185,370	552,082	87.18%

7.3 Limiting Cooling Water Flow Rate Analysis

The limiting cooling water flow analysis calculated the lowest possible cooling water flow that would provide a thermal margin of approximately 30% ± 5% for the 1(2)VY04A coolers with an adjusted design fouling of 0.002 air-side and 0.002 tube-side. The results of the iterations to identify the limiting flow rate are summarized in Table 10. The PROTO-HX™ reports associated with the limiting flow analysis are included as Attachment I.

Table 10: Limiting Cooling Water Flow Rate at Reference Conditions (f= 0.0020/0.0020)

Cooler	Limiting Flow Rate	$q_{required}$ (BTU/hr)	$q_{available}$ (BTU/hr)	Margin (BTU/hr)	Margin (%)
1(2)VY04A	66.5	633,288	818,271	184,983	29.20%

The uncertainty in the analytical methodology used to identify the limiting flow for 1(2)VY04A is presented in Attachment J. The result of the uncertainty assessment is that the uncertainty in the PROTO-HX™ extrapolated heat transfer rate ranges from ± 5.81% to ± 6.99% for the front coil and ± 4.33% to ± 6.36% for the back coil for the ranges of cooling water flow evaluated. An uncertainty of ± 7.00% and ± 6.40% is used for the front and back coils respectively to conservatively bound the analysis of Attachment J. The combined analytical uncertainty for the two coils together is taken as the square root of the sum of the squares of the front and back coil contributions. Accordingly, the overall analytical uncertainty for 1(2)VY04A is expressed as:

$$U_{analytical} = \sqrt{(U_{front})^2 + (U_{back})^2}$$

$$U_{analytical} = \sqrt{(0.070)^2 + (0.064)^2}$$

$U_{analytical}$ = 0.095

$U_{analytical}$ = 9.5%

The adjusted thermal margin is calculated using Equation (11) after subtracting the uncertainty from the available heat rate. The results are presented in Table 10 below.

Table 11: Limiting Cooling Water Flow Rate at Reference Conditions (*f* = 0.0020/0.0020)

Cooler	Limiting Flow Rate	$q_{required}$ (BTU/hr)	$q_{available}$ (BTU/hr)	Nominal Margin (%)	Adjusted Margin (%)
1(2)VY01A	66.5	633,288	740,535	107,247	16.93%

7.4 Fouling Sensitivity Analysis

The results of the fouling sensitivity analysis are included in Table 11. The PROTO-HX™ reports associated with the fouling sensitivity analysis and a graphical presentation of the results are included as Attachment M. It should be noted that neither the Table below or the figure in Attachment M have taken analytical uncertainty into account since the intent of this exercise is to assess the change in thermal margin (i.e., the slope of the curve in Attachment M). Analytical uncertainty treated as a bias on the results will have a negligible effect on the slope of the curve. Consideration of uncertainty would, however, change the point at which a thermal margin of 0% is reached.

Table 12: Fouling Sensitivity Analysis – 1(2)VY04A at 66.5 gpm

Air-Side *f*	Tube-Side *f*	Required q	Available q	%Margin
0.0020	0.0000	633,288	544,475 324,952 869,427	37.29%
0.0020	0.0020	633,288	487,103 331,168 818,271	29.21%
0.0020	0.0040	633,288	440,315 331,663 771,978	21.90%

8. CONCLUSIONS

Two models for the LaSalle County Station Units 1 & 2 NE Cubicle Area Coolers were developed using PROTO-HX™ Version 3.01. The models were benchmarked and validated using the performance specifications provided by the cooler vendor. The close correlation with vendor specified and model predicted thermal performance confirms that the models are to be considered acceptable for use in the GL 89-13 heat exchanger testing program and related performance analysis.

The available thermal margin for the coolers has been defined for the nameplate rated flow of 200 gpm and for a reduced flow rate of 66.5 gpm in support of service water system flow requirements. Inclusion of a conservative assessment of the uncertainty in the analytical methods of PROTO-HX™ has provided high confidence in the thermal margins defined by the model for all cases.

The front coil model database is saved under file name vy-04a-f.phx, with a file size of 1,409,024 bytes, and a file date and time of 7/10/98 at 4:09:12 pm. The back coil model database is saved under file name vy-04a-b.phx, with a file size of 1,409,024 bytes, and a file date and time of 7/10/98 at 4:09:30 pm. The saved models are set up to run the 66.5 gpm case with adjusted design fouling factors of 0.002 air-side and 0.002 tube-side. The database files are included as Attachment N.

9. REFERENCES

1. Heat Exchanger Thermal Performance Modeling Software Program PROTO-HX™ Version 3.01 Software Validation and Verification Report (SVVR) SQA No. SVVR-93948-02, Revision E, dated 11/5/97

2. LaSalle Calculation L-001024, Revision 2, LPCS Pump Cubicle Cooler Ventilation System

3. Crane Technical Paper No. 410, Flow of Fluids Through Valves, Fittings, and Pipe, 25th Printing, 1991, Crane Company

4. LaSalle Station Updated Final Safety Analysis Report, Table 3.11-7, Harsh Environment Zone H5 -- Bounding Environmental Conditions for HELB Areas in the Reactor Building (Attachment A)

5. LaSalle Station Updated Final Safety Analysis Report, Section 9.2.1, ECCS Equipment Cooling Water System (excerpt - Attachment A)

6. LaSalle Station Updated Final Safety Analysis Report, Section 9.2.6, Ultimate Heat Sink (excerpt - Attachment A)

7. Drawing 28SW404543, "CSCS Equipment Area Cooling Coils," original issue, 7/21/76 (Attachment A)

8. LaSalle Calculation L-000581, Revision 0, Evaluation of the CSCS Cubicle Area Coolers Operation with a Reduced Cooling Water Inlet Temperature

9. Drawing M-87, Sheet 3, "CSCS Equipment Cooling Water System," Revision F dated 5/4/88

10. Drawing M-134, Sheet 3, "CSCS Equipment Cooling Water System," Revision F dated 5/25/82

11. Bahnson Drawings 2605-1-11,12,13, & 14 (Attachment A)

12. Standards of the Tubular Exchanger Manufacturers Association (TEMA), Seventh Edition, 1988

13. Specification Number J-2582, Heat Exchange Coils and Cabinets, La Salle County - Units 1 and 2, Revision 1, dated 1/16/75 (excerpt - Attachment A)

14. Proto-Power Calculation 96-069, Revision -, Fluid Properties - Moist Air - Range 8° to 300°F

15. *Compact Heat Exchangers*, W.M. Kays and A.L. London, McGraw Hill, Third Edition, 1984. (excerpt - Attachment C)

16. 1997 ASHRAE Handbook -- Fundamentals, inch pound Edition, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA (excerpt - Attachment A)

17. Drawing M-1366, Sheet 2, "Reactor Building Ventilation System -- Elevation 694'-6" West," Revision F dated 5/17/82

PROTO-POWER CORPORATION **GROTON, CONNECTICUT**	CALC NO. 97-198	REV A	PAGE 30 OF 30
	ORIGINATOR L. Philpot		DATE 7/13/98
	VERIFIED BY M. Aboye		JOB NO. 31-003
CLIENT Commonwealth Edison	PROJECT LaSalle Station GL 89-13 Heat Exchanger Testing		
TITLE VY Cooler Thermal Performance Model -- 1(2)VY04A			

18. Drawing M-1464, "CSCS Equipment Cooling System," Revision B dated 5/12/88
19. Drawing M-1465, "CSCS Equipment Cooling System," Revision B dated 5/12/88
20. Coil Walkdown Data, ComEd NDIT No. LS-0847, dated 7/6/98 (Attachment L)

Attachment A to
Proto-Power Calculation
97-198
Revision A

Reference 4

TABLE 3.11-7

HARSH ENVIRONMENT ZONE H5 - BOUNDING ENVIRONMENTAL CONDITIONS FOR HELB AREAS IN THE REACTOR BUILDING

Temperature (°F)	212	150	150
Pressure	7 in. W.G.*	7 in. W.G.	Atmospheric
Relative Humidity	Steam	100%	90%
Duration	0-6 hr	6-12 hr	12 hr to 100 days
Radiation	1 x 10^7 rads gamma (integrated)		

1(2)VY04A

NOTE: The bounding radiation dose ≥ (normal service radiation dose integrated over 40 years + accident dose + 10% margin on the accident dose per IEEE 323-1974, Section 6.3.1.5)

*Transient peak pressure of 40 psig can occur within the first 10 seconds of the line break event. However, venting and subsequent depressurization to atmospheric pressure occurs very rapidly.

Reference 5

4. RHR pump seal cooler ('A' and 'B' RHR pumps only) - 20 gpm
5. LPCS pump motor cooling coil - 4 gpm
6. northwest cubicle area cooling coil - 150 gpm
7. southwest cubicle area cooling coil - 150 gpm
8. northeast cubicle area cooling coil - 200 gpm
9. southeast cubicle area cooling coil - 180 gpm
10. emergency makeup to fuel pool - 50 gpm minimum
11. containment flood - 300 gpm maximum.

b. System classifications are as shown in Section 3.2. All portions of this system are protected from the effects of tornados, missiles, pipe whip, and flooding.

c. To meet single failure criteria, the CSCS-ECWS for each unit is designed as three independent subsystems, one of which is shared between units (Drawing Nos. M-87 and M-134).

d. Strainers are provided to prevent plugging of cooled component heat transfer passages. All strainers include provisions for backwashing without significantly affecting system operation.

Organic fouling of heat transfer surfaces will be minimized by the chemical feed system which will treat the service water tunnel inlet flow with oxidizing biocides. However, the chemical feed system should not be considered auxiliary equipment required for the CSCS-ECW systems to perform their function. Therefore, the operability of the CSCS-ECW systems should not be tied to the operability of the chemical feed system. Connections and isolation valves are also provided immediately upstream and downstream of each cooled component for injection and circulation of biocidal agents, if necessary.

e. To detect leakage of radioactivity to the environment, radiation monitors are installed in the CSCS-ECWS immediately downstream of cooled components that contain radioactive fluids. The CSCS-ECWS discharge lines from these components are capable of remote manual isolation from the main control room.

f. Design of system piping and components is based on a 40-year life. Exterior surfaces of all buried system piping is protected by bituminous coatings and wrappings and provisions for cathodic protection are installed where such protection is found to be required based on electrical potential measurements. The design of all system piping includes a corrosion allowance of at least 0.08 inches.

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Reference 6

the normally closed portions the integrity and operability are checked.

9.2.6 Ultimate Heat Sink

The ultimate heat sink (UHS) provides sufficient cooling water to permit the safe shutdown and cooldown of the station for 30 days with no makeup for both normal and accident conditions.

9.2.6.1 Design Bases

9.2.6.1.1 Safety Design Bases

The ultimate heat sink has the following design bases:

a. to provide sufficient water volume permitting a safe shutdown and cooldown of the station for 30 days with no water makeup for both normal operating and accident conditions - the maximum permissible water temperature supplied to the plant is taken as 100° F;

b. to withstand the most severe postulated natural phenomenon as discussed in Chapter 2.0;

c. to withstand the postulated site-related incidents as discussed in Subsection 2.5.5; and

d. to provide water for fire protection equipment.

A more detailed physical description of the ultimate heat sink is provided in Sections 2.4 and 2.5.

9.2.6.1.2 Power Generation Design Bases

The ultimate heat sink, as a safety system, is not used during normal plant operations. Therefore, the ultimate heat sink has no power generation bases.

9.2.6.2 System Description

In the unlikely event that the main dike is breached, the cooling lake for the La Salle County Station is designed to hold 460 acre-feet of water with a surface area of 83 acres. This remaining water constitutes the ultimate heat sink for the station, and has a depth of approximately 5 feet and a top water elevation established at 690 feet. Figures 2.4-4 and 9.2-1 illustrate the physical layout and area capacity of the ultimate heat sink.

9.2.6.3 Safety Evaluation

The station's ultimate water requirements (Units 1 and 2) in gpm are summarized below.

INDIVIDUAL COIL DATA					PERFORMANCE DATA (TOTAL FOR COIL BANK)														
TUBE FACE	ROWS	CIRCUIT-ING	FACE AREA (SQ.FT.)	MARK FOR	SCFM	ENT. AIR TEMP(°F) DB/WB	LVG. AIR TEMP(°F) DB/WB	ENT. WATER TEMP(°F)	LVG. WATER TEMP(°F)	WATER GPM	TOTAL HEAT TRANSFER (BTU/H)(10⁶)	AIR SIDE PRESS DROP (IN. H2O)	TUBE SIDE PRESS DROP (FT. OF H2O)	DESIGN PRESSURE (PSIG)	DESIGN TEMP.(°F)	COIL QTY. PER UNIT	SHIPPING WGT.(LBS) PER COIL	[illegible] WGT.(LBS) PER COIL
20	4	DOUBLE	21.4	1VY04A.	27450	150./92.	109/84.0	105.	117.31	200.	1.194	1.45	12.5	250.	200.	2	500	580
20	8	DOUBLE	21.4	2VY04A												2	880	1030

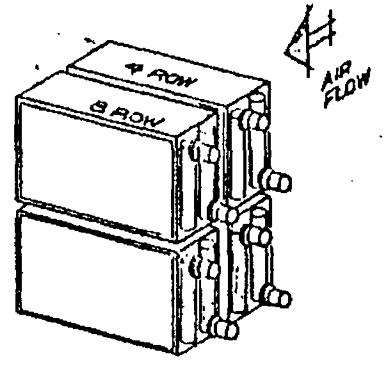
MATERIAL SPECIFICATIONS

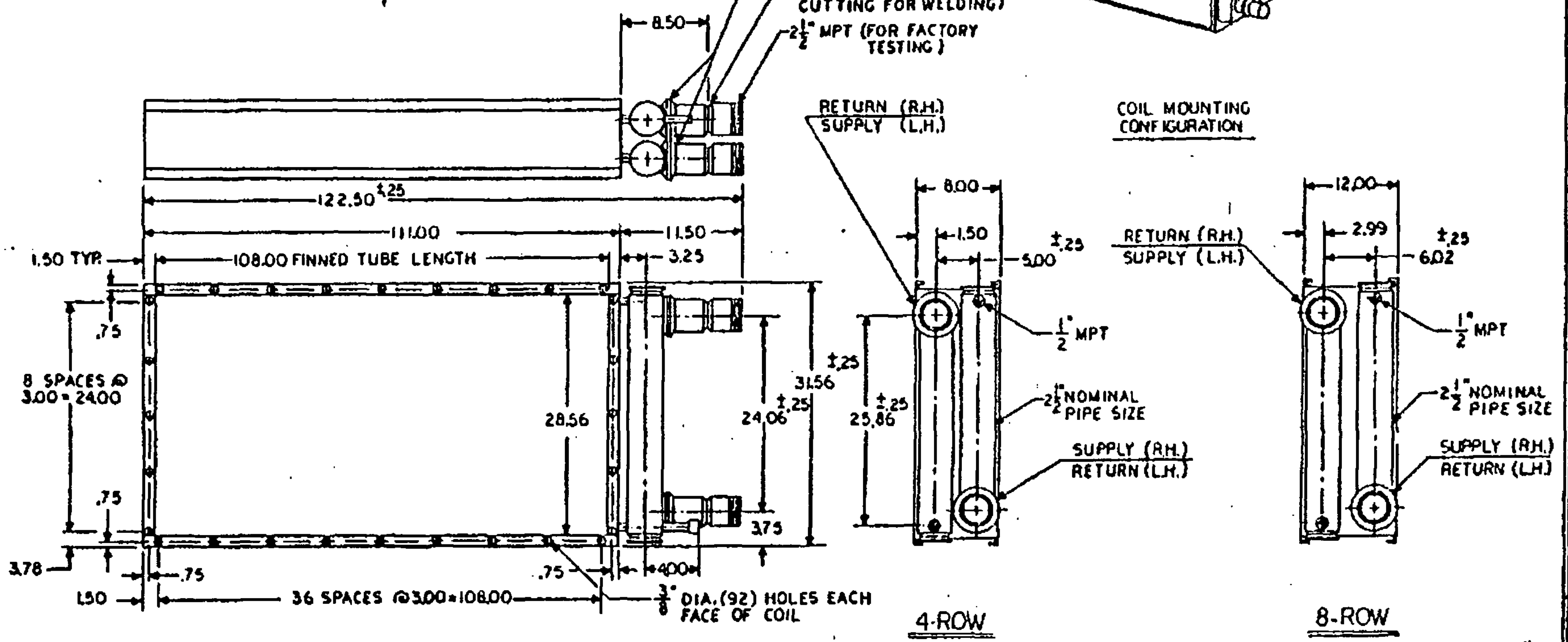
TUBES - $\frac{5}{8}$ O.D. ASME SB75 COPPER, .049 WALL THICKNESS.

FINS - ASTM B209 ALUM. 0.012 IN. THK. SPIRAL TYPE MECHANICAL BOND, 10.0 FINS/INCH.

HEADERS - $2\frac{1}{2}$" NOM. SCH. 80 BLACK STEEL PIPE ASTM A53

CASING - ASTM A526, 14GA. GALV. STEEL





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GENERAL TOLERANCES
DECIMALS ±.12
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES

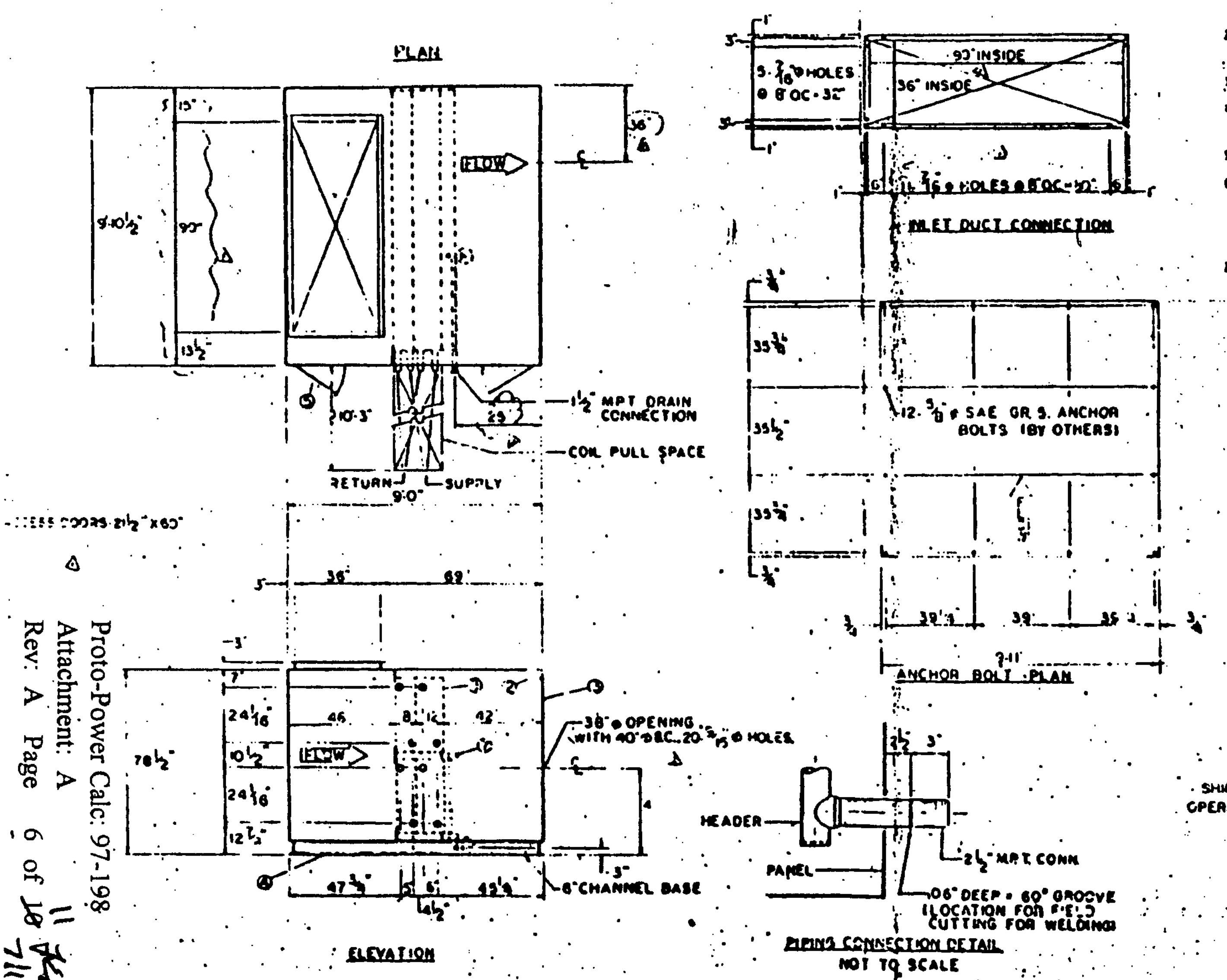
JOB NAME LASALLE COUNTY POWER STATION-UNIT #1/2
JOB LOCATION SENECA, ILLINOIS
BUYER COMMONWEALTH EDISON COMPANY
BUYER NO. 194871 CARRIER NO. 6700D2039
DIMENSIONS CERTIFIED BY J. Lockwood DATE 7-26-76

DRAWN BY	THOMSON	6-23-76
CH'KD BY	RDB	7-26-76

DATE	SUPERSEDES		EQUIPMENT NO.(S)	DWG. NO.	REV.
		SAFETY RELATED COOLING COILS-CSCS EQUIPMENT AREA	1VY04A, 2VY04A	28SW404563	

Reference 7

Carrier



BILL OF MATERIALS

1. UNIT COOLER DESIGNED TO COOL 27,450 SCFM FROM [illegible] USING 290 GPM OF WATER FROM 105°F TO 117.3°F [illegible] FOLLOWING CONSTRUCTION AND EQUIPMENT. FACTORY ORDER NO. [illegible]
2. GROUP OF INTEGRAL STRUCTURAL FRAMING (SPEC. 7). [illegible] 8-00530-13[illegible].
3. GROUP OF ENCLOSURE PANELS (SPEC. 33). FACTORY ORDER NO. [illegible]
4. STRUCTURAL STEEL BASE WITH LIFTING LUGS (SPEC. 36). FACTORY ORDER NO. 8-00530-130C.
5. ACCESS DOORS (SPEC. 40). FACTORY ORDER NO. [illegible]
6. BANK OF COOLING COILS RATED 1,194,..30 BTU/H AIR PRESSURE DROP 1.45 IN. WATER, WATER PRESSURE DROP 12.5 FT. WATER CONSISTING OF 2 COOLING COILS 30 BY [illegible] 100 IN., 6 ROWS DOUBLE CIRCUIT AND 2 COOLING COILS 30 BY [illegible] 100 IN., 8 ROWS DOUBLE CIRCUIT (SPEC. 6 & 6A). FACTORY ORDER NO. [illegible]
7. COOLING COIL DRIP PANS CONSTRUCTED FROM 16 GAUGE 304 STAINLESS STEEL. FACTORY ORDER NO. 8-00530-130F.

SARGENT & LUNDY SPEC J-2592

SAFETY RELATED

SEE DWG. 2605-1-6 FOR MATL SPEC'S
SHIPPING WEIGHT 5130#
OPERATING WEIGHT 5430#

0 6 12
GRAPHIC SCALE

RIGHT HAND UNIT
ALL DIMENSIONS ± ⅛

LASALLE COUNTY UNIT 1&2
SENECA, ILLINOIS
COMMONWEALTH EDISON

Reference 11

CSCS EQUIP AREA COIL CABINETS
1VY04A

DRAWN BY
CHECKED BY

BAC-40U-15 2

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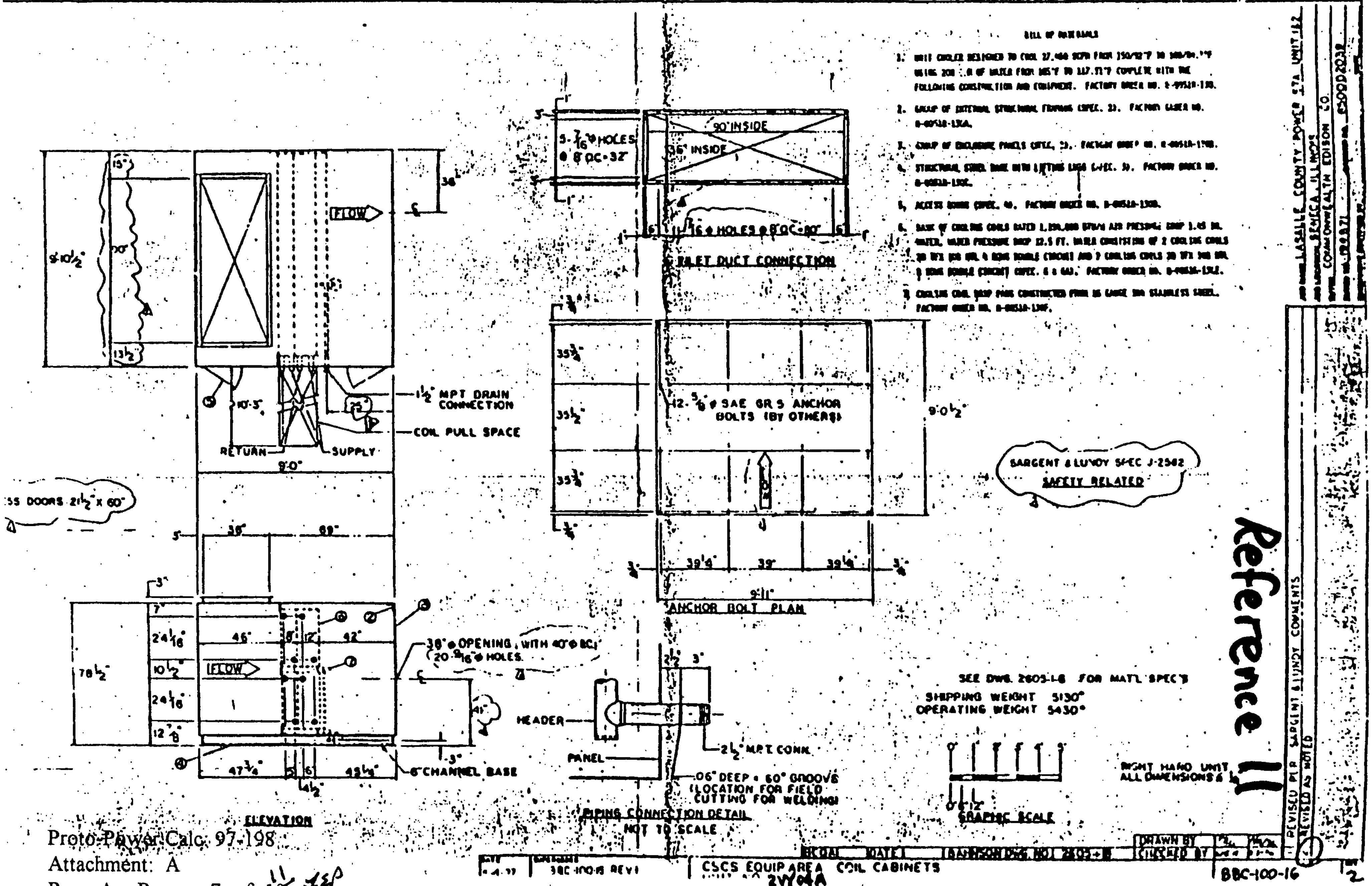

BILL OF MATERIALS

1. UNIT COOLER DESIGNED TO COOL 27,400 SCFM FROM 150/127°F TO 108/94.?°F USING 200 GPM OF WATER FROM 105°F TO 117.??°F COMPLETE WITH THE FOLLOWING CONSTRUCTION AND EQUIPMENT. FACTORY ORDER NO. [illegible]-130.
2. GROUP OF EXTERNAL STRUCTURAL FRAMING (SPEC. 2). FACTORY ORDER NO. 0-00510-130A.
3. GROUP OF ENCLOSURE PANELS (SPEC. 2). FACTORY ORDER NO. 0-00510-130B.
4. STRUCTURAL STEEL BASE WITH LIFTING LUGS (SPEC. 3). FACTORY ORDER NO. 0-00510-130C.
5. ACCESS DOORS (SPEC. 4). FACTORY ORDER NO. 0-00510-130D.
6. BANK OF COOLING COILS RATED [illegible] BTU/H AIR PRESSURE DROP 1.45 IN. WATER, WATER PRESSURE DROP 12.5 FT. BANK CONSISTING OF 2 COOLING COILS 30 TFS 108 IN. 4 ROWS DOUBLE CIRCUIT AND 2 COOLING COILS 30 TFS 108 IN. 4 ROWS DOUBLE CIRCUIT (SPEC. 5 & 6A). FACTORY ORDER NO. 0-00510-130E.
7. COOLING COIL DRIP PANS CONSTRUCTED FROM 16 GAUGE 304 STAINLESS STEEL. FACTORY ORDER NO. 0-00510-130F.

SARGENT & LUNDY SPEC J-2542
SAFETY RELATED

SEE DWG. 2605-L6 FOR MAT'L SPEC'S
SHIPPING WEIGHT 5130#
OPERATING WEIGHT 5430#

RIGHT HAND UNIT
ALL DIMENSIONS ± 1/8

Reference 11

LASALLE COUNTY POWER STA. UNIT 1&2
SENECA, ILLINOIS
COMMONWEALTH EDISON CO.

REVISED PER SARGENT & LUNDY COMMENTS
REVISED AS NOTED

BBC-100-16 REV 1
CSCS EQUIP AREA COIL CABINETS
2VY04A
DRAWN BY
CHECKED BY
BBC-100-16
2

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GENERAL
QUALITY ASSURANCE
PROCEDURE

SARGENT & LUNDY
ENGINEERS
CHICAGO

TITLE & APPROVAL PAGE

Reference 13

"SAFETY RELATED ITEMS ARE PART OF THIS SPECIFICATION"

Client CECO

Specification Title Heat Exchange Coils and Cabinets

Specification Number J-2582

Project Identification La Salle County - Units 1 and 2

Project Number 4266-00/4267-00

Department Mechanical/HVAC

REV	DATE	PREPARER	APPROVER	PURPOSE OF ISSUE
1	1-16-75	P. N. Mehrotra	W K Brown	Issue to CECO for bids.

	Function or Service..........	Control Room	Auxiliary Electric Equipment	Primary Contain-ment Vent.	CSCS Eqpt. Area Cooling	CSCS Eqpt. Area Cooling	CSCS Eqpt. Area Cooling	
	Equipment Numbers.............	OVC02AA OVC02AB	OVE01AA OVE01AB	1VP03AA 1VP03AB 2VP03AA 2VP03AB	1VY01A 1VY02A 2VY01A 2VY02A	1VY03A 2VY03A	1VY04A 2VY04A	
	Safety related or Nonsafety related (SR or NSR)..........	SR	SR	NSR	SR and ASME III	SR and ASME III	SR and ASME III	
403.	PERFORMANCE DATA (HEAT EXCHANGE COIL CABINETS)							
403.1	Mode of Operation........... ...	Cooling	Cooling	Cooling	Cooling	Cooling	Cooling	
a.	Entering Air Dry Bulb......(°F)	81.8	81.9	135	150	150	150	Add.1
b.	Entering Air Wet Bulb......(°F)	63.1	63.2	92	______	______	______	Add.1
c.	Leaving Air Dry Bulb.......(°F)	54.3	54.9	65	110	110	110	Add.1
d.	Leaving Air Wet Bulb.......(°F)	52.8	53.2	63	______	______	______	Add.1
e.	Actual Air Quantity at 70°F, 40% RH and Site Elevation ....(ft^3/min)	26340	31300	50000	18000	26400	28500	
f.	Standard Air Quantity at .075 lb/ft^3...........(Std ft^3/min)	25380	30100	48150	17330	25420	27450	
g.	Cooling Medium.................	R-22	R-22	Chilled Water	Water	Water	Water	
h.	Evaporator Refrigerant Tempera-ture.....................(°F)	42	42	______	______	______	______	Add.1
i.	Entering Water Temperature.(°F)	______	______	46	105.	105.	105.	
j.	Maximum Water Quantity(gal/min)	______	______	1200	150.	220.	240	
k.	Minimum Total Heat Exchange Capacity ....(Btu/h)	797,000	936,000	6.55×10^6	748,700	1.1×10^6	1.19×10^6	
l.	Minimum Sensible Heat Exchange Capacity ....(Btu/h)	725,000	847,000	3.63×10^6	748,700	1.1×10^6	1.19×10^6	
m.	Maximum Coil Face Velocity ....(ft/min)	600	600	600	700	700	700	

4-7

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Reference 13

J-2582
Add. 1

Reference 16

Table 1A Heating and Wind Design Conditions—United States

							Heating DB		Extreme Wind Speed			Coldest Month WS/MDB				MWS/MWD to DB				Annual Extreme Daily			
												0.4%		1%		99.6%		0.4%		Mean DB		StdD DB	
Station	WMO#	Lat.	Long.	Elev. ft	StdP psia	Dates	99.6%	99%	1%	2.5%	5%	WS	MDB	WS	MDB	MWS	PWD	MWS	PWD	Max	Min	Max	Min
West Palm Beach	722030	26.68	80.12	20	14.685	6193	43	47	24	21	19	24	69	21	70	9	320	12	110	94	35	2.0	5.0
GEORGIA																							
Albany	722160	31.53	84.18	194	14.593	8293	27	30	19	17	15	19	50	18	50	4	360	9	250	100	17	2.2	7.2
Athens	723110	33.95	83.32	810	14.270	6193	20	25	19	17	15	20	40	18	40	10	290	9	270	98	11	3.5	6.6
Atlanta	722190	33.65	84.42	1033	14.155	6193	18	23	22	19	17	23	37	21	36	12	320	9	300	96	9	3.5	7.3
Augusta	722180	33.37	81.97	148	14.617	6193	21	25	20	18	15	21	45	19	46	5	290	9	250	100	13	3.7	5.6
Brunswick	722137	31.15	81.38	20	14.685	8293	30	34	18	17	16	19	49	18	49	8	350	10	250	98	22	2.5	7.2
Columbus, Fort Benning	722250	32.33	85.00	233	14.572	8293	23	27	16	13	11	17	46	15	46	3	320	5	240	100	14	2.9	6.7
Columbus, Metro Airport	722255	32.52	84.93	397	14.486	6193	23	27	17	15	14	15	44	16	46	7	310	9	310	99	14	2.3	6.1
Macon	722170	32.70	83.65	361	14.505	6193	23	27	19	17	15	20	46	18	45	7	320	9	270	100	14	2.7	6.4
Marietta, Dobbins AFB	722270	33.92	84.52	1070	14.136	8293	21	26	18	16	13	20	35	18	38	9	340	6	300	97	12	3.6	6.7
Rome	723200	34.35	85.17	643	14.357	8293	15	21	14	12	10	14	42	13	42	5	340	6	270	98	4	3.8	7.0
Savannah	722070	32.13	81.20	49	14.669	6193	26	29	20	17	15	21	49	19	49	7	270	9	270	98	18	3.0	5.4
Valdosta, Moody AFB	747810	30.97	83.20	233	14.572	8293	30	34	15	13	12	16	53	14	52	4	360	5	300	99	21	2.5	7.6
Valdosta, Regional Airport	722166	30.78	83.28	203	14.588	8293	28	31	17	15	14	18	55	16	56	4	340	8	300	99	17	3.2	7.7
Waycross	722130	31.25	82.40	151	14.615	8293	29	32	16	14	12	16	52	14	52	4	250	7	240	98	21	7	7.6
HAWAII																							
Ewa, Barbers Point NAS	911780	21.32	158.07	49	14.669	8293	59	61	20	18	16	22	73	19	75	5	40	11	60	93	35	1.6	21.4
Hilo	912850	19.72	155.07	36	14.676	6193	61	63	19	16	14	21	76	18	76	7	230	12	110	88	58	1.6	1.8
Honolulu	911820	21.35	157.93	16	14.687	6193	61	63	23	21	20	23	74	21	75	5	320	15	60	91	58	1.9	2.2
Kahului	911900	20.90	156.43	66	14.661	6193	59	61	27	25	24	32	76	28	76	6	160	19	50	92	54	1.5	7.4
Kaneohe, MCAS	911760	21.45	157.77	10	14.690	8293	67	68	20	18	17	21	74	19	74	7	190	10	70	88	40	1.4	29.0
Lihue	911650	21.98	159.35	148	14.617	6193	60	62	26	24	21	25	73	23	73	8	270	14	60	87	57	1.4	3.0
Molokai	911860	21.15	157.10	449	14.458	8293	60	61	24	22	21	22	74	21	74	4	70	13	60	92	43	4	22.0
IDAHO																							
Boise	726810	43.57	116.22	2867	13.235	6193	2	9	24	21	18	22	37	19	37	6	130	11	320	103	-4	2.7	9.1
Burley	725867	42.55	113.77	4150	12.621	8293	−5	2	23	21	19	23	30	22	28	7	60	8	280	98	−11	4	8.5
Idaho Falls	725785	43.52	112.07	4741	12.346	8293	−12	−6	27	23	21	28	32	23	29	7	360	12	180	96	−20	3.6	9.0
Lewiston	727830	46.38	117.02	1437	13.948	8293	6	15	20	17	14	24	38	20	40	5	280	7	310	103	3	2.7	9.9
Mountain Home, AFB	726815	43.05	115.87	2995	13.173	8293	0	5	23	21	18	23	33	21	31	2	90	8	350	105	−6	3.2	8.5
Mullan	727836	47.47	115.80	3317	13.017	8293	−1	7	10	10	9	11	18	9	21	2	10	4	10	92	−7	2	7.9
Pocatello	725780	42.92	112.60	4478	12.468	6193	−7	0	29	25	23	30	36	27	36	6	50	11	250	98	−15	2.3	9.1
ILLINOIS																							
Belleville, Scott AFB	724338	38.55	89.85	453	14.457	8293	3	10	21	18	15	23	32	20	31	7	360	7	190	100	−3	3.1	7.2
Chicago, Meigs Field	725340	41.78	87.75	623	14.367	8293	−4	3	23	22	19	26	17	23	30	12	240	13	220	97	−10	3.2	8.1
Chicago, O'Hare Int'l A	725300	41.98	87.90	673	14.342	6193	−6	−1	26	23	21	27	24	23	23	10	270	12	230	96	−12	2.8	6.5
Decatur	725316	39.83	88.87	682	14.337	8293	−2	3	24	22	20	27	24	24	27	13	310	12	210	99	−10	5.8	[illegible]
Glenview, NAS	725306	42.08	87.82	653	14.352	8293	−3	4	22	19	17	23	17	20	25	11	250	10	240	98	−10	3.1	7.7
Marseilles	744600	41.37	88.68	738	14.308	8293	−5	1	26	22	20	28	18	25	21	12	290	10	250	96	−11	4	5.9
Moline/Davenport IA	725440	41.45	90.52	594	14.383	6193	−8	−3	26	23	20	28	16	24	18	9	290	12	200	97	−14	2.7	6.0
Peoria	725320	40.67	89.68	663	14.347	6193	−6	−1	25	22	20	26	16	23	19	9	290	11	180	96	−12	3.3	6.1
Quincy	724396	39.95	91.20	768	14.292	8293	−4	2	26	23	20	28	23	24	22	12	330	12	210	97	−10	3.6	[illegible]
Rockford	725430	42.20	89.10	741	14.306	6193	−10	−4	26	23	21	26	18	23	20	9	290	13	200	95	−16	3.1	5.5
Springfield	724390	39.85	89.67	614	14.373	6193	−4	2	25	23	21	27	25	24	27	10	270	12	230	97	−11	2.8	5.5
West Chicago	725305	41.92	88.25	758	14.297	8293	−7	0	23	21	19	25	13	23	20	11	290	11	240	96	−14	3.2	7.7
INDIANA																							
Evansville	724320	38.05	87.53	387	14.491	6193	3	9	22	19	17	22	33	20	34	7	320	9	240	97	−4	2.7	8.5
Fort Wayne	725330	41.00	85.20	827	14.262	6193	−4	2	25	23	20	27	19	24	22	10	250	12	230	95	−11	3.6	5.2
Indianapolis	724380	39.73	86.27	807	14.272	6193	−3	3	24	21	19	25	26	22	27	8	230	11	230	94	−10	2.8	6.8
Lafayette, Purdue Univ	724386	40.42	86.93	607	14.376	8293	−5	3	22	20	18	24	26	22	27	9	270	12	220	97	−11	3.8	7.7
Peru, Grissom AFB	725335	40.65	86.15	810	14.270	8293	-3	4	24	21	18	29	20	24	22	11	270	9	210	96	−8	3.8	7.4
South Bend	725350	41.70	86.32	774	14.289	6193	-2	3	25	23	20	26	22	23	23	13	230	12	230	95	−10	3.3	5.8
Terre Haute	724373	39.45	87.32	584	14.388	8293	-3	5	23	20	18	23	31	21	32	8	150	11	230	96	−10	3.2	7.9
IOWA																							
Burlington	725455	40.78	91.13	699	14.328	8293	-4	1	21	19	17	24	12	21	18	9	310	11	200	98	−10	4	6.8
Cedar Rapids	725450	41.88	91.70	869	14.240	8293	11	-5	25	22	20	29	12	26	14	10	300	11	180	96	-15	3.6	5.4
Des Moines	725460	41.53	93.65	965	14.190	6193	9	-4	27	24	21	28	14	24	19	11	320	12	180	98	-15	3.4	5.1
Fort Dodge	725490	42.55	94.18	1165	14.087	8293	-13	-7	27	23	21	29	10	26	10	11	340	11	190	96	-17	4.9	4.9
Lamoni	725466	40.62	93.95	1122	14.109	8293	-6	0	19	17	15	21	23	19	20	7	320	9	210	99	-12	4.3	6.8
Mason City	725485	43.15	93.33	1214	14.062	6193	−15	−10	27	23	22	30	9	27	12	12	300	14	200	97	-23	3.6	11.4
Ottumwa	725465	41.10	92.45	846	14.251	8293	5	0	29	26	23	31	20	28	24	13	320	15	200	98	12	4	6.8
Sioux City	725570	42.40	96.38	1102	14.119	6193	-11	−6	29	25	22	31	14	28	16	11	320	14	180	99	18	3.6	4.7
Spencer	726500	43.17	95.15	1339	13.998	8293	16	−11	24	22	20	25	13	23	13	10	300	12	180	99	-20	6.3	4.0
Waterloo	725480	42.55	92.40	879	14.234	6193	14	−9	27	24	22	29	10	25	13	9	300	13	180	96	-20	3.5	5.9
KANSAS																							
Concordia	724580	39.55	97.65	1483	13.925	8293	−4	3	28	25	22	28	32	25	32	13	360	16	10	104	−8	4	9.4
Dodge City	724510	37.77	99.97	2592	13.370	6193	0	6	30	27	24	31	31	27	32	13	10	17	200	104	−6	2.8	5.6
Ft Riley, Marshall AAF	724550	39.05	96.77	1066	14.138	8293	−2	5	21	18	16	20	39	18	37	5	350	9	180	104	−5	3.1	9.0
Garden City	724515	37.93	100.72	2890	13.224	8293	−3	4	30	26	23	29	32	25	34	12	360	16	190	104	−9	2.7	6.5
Goodland	724650	39.37	101.70	3688	12.840	6193	−3	2	32	28	24	31	27	27	30	12	270	13	180	102	−11	2.9	6.6

WMO# = World Meteorological Organization number
Lat = latitude
Long. = longitude
Elev = elevation, ft
StdP = standard pressure at station elevation, psia
DB = dry-bulb temperature, °F
WS = wind speed, mph

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Reference 16

Table 3 Properties of Solids

	Specific Heat, Btu/lb-°F	Density, lb/ft^3	Thermal Conductivity, Btu/h-ft-°F	Emissivity	
Material Description				Ratio	Surface Condition
Aluminum (alloy 1100)	0.214^{h}	171^{u}	128^{u}	0.09^{n} 0.20^{n}	Commercial sheet Heavily oxidized
Aluminum bronze (76% Cu, 22% Zn, 2% Al)	0.09^{u}	517^{v}	58^{v}		
Asbestos: Fiber	0.25^{h}	150^{u}	0.097^{u}		
Insulation	0.20^{f}	36^{a}	0.092^{h}	0.93^{h}	"Paper"
Ashes, wood	0.20^{f}	40^{h}	0.041^{h} (122)		
Asphalt	0.22^{h}	132^{h}	0.43^{h}		
Bakelite	0.35^{h}	81^{u}	9.7^{u}		
Bell metal	0.086^{l} (122)				
Bismuth tin	0.040^{*}		37.6^{*}		
Brick, building	0.2^{h}	123^{v}	0.4^{h}	0.93^{*}	
Brass: Red (85% Cu, 15% Zn)	0.09^{u}	548^{v}	87^{a}	0.030^{h}	Highly polished
Yellow (65% Cu, 35% Zn)	0.09^{u}	519^{v}	69^{u}	0.033^{b}	Highly polished
Bronze	0.104^{t}	530^{j}	17^{d} (32)		
Cadmium	0.055^{a}	540^{f}	53.7^{h}	0.02^{d}	
Carbon (gas retort)	0.17^{a}		0.20^{h} (2)	0.81^{a}	
Cardboard			0.04^{h}		
Cellulose	0.32^{b}	3.4^{t}	0.033^{t}		
Cement (portland clinker)	0.16^{h}	120^{j}	0.017^{j}		
Chalk	0.215^{t}	143^{t}	0.48^{*}	0.34^{*}	About 250°F
Charcoal (wood)	0.20^{j}	15^{a}	0.03^{a} (392)		
Chrome brick	0.17^{h}	200^{b}	0.67^{b}		
Clay	0.22^{h}	63^{t}			
Coal	0.3^{b}	90^{j}	0.098^{f} (32)		
Coal tars	0.35^{h} (104)	75^{h}	0.07^{h}		
Coke (petroleum, powdered)	0.36^{h} (752)	62^{h}	0.55^{b} (752)		
Concrete (stone)	0.156^{h} (392)	144^{b}	0.54^{b}		
Copper (electrolytic)	0.092^{u}	556^{u}	227^{a}	0.072^{n}	Commercial, shiny
Cork (granulated)	0.485^{t}	5.4^{t}	0.028^{t} (23)		
Cotton (fiber)	0.319^{u}	95^{u}	0.024^{u}		
Cryolite ($AlF_3 \cdot 3NaF$)	0.253^{h}	181^{h}			
Diamond	0.147^{h}	151^{t}	27^{l}		
Earth (dry and packed)		95^{t}	0.037^{*}	0.41^{*}	
Felt		20.6^{b}	0.03^{b}		
Fireclay brick	0.198^{b} (212)	112^{t}	0.58^{b} (392)	0.75^{n}	At 1832°F
Fluorspar (CaF_2)	0.21^{h}	199^{v}	0.63^{v}		
German silver (nickel silver)	0.09^{a}	545^{u}	19^{u}	0.135^{n}	Polished
Glass: Crown (soda-lime)	0.18^{b}	154^{u}	0.59^{t} (200)	0.94^{n}	Smooth
Flint (lead)	0.117^{b}	267^{u}	0.79^{r}		
Heat-resistant	0.20^{h}	139^{t}	0.59^{t} (200)		
"Wool"	0.157^{h}	3.25^{t}	0.022^{t}		
Gold	0.0312^{u}	1208^{u}	172^{t}	0.02^{n}	Highly polished
Graphite: Powder	0.165^{*}		0.106^{*}		
Impervious	0.16^{u}	117^{u}	75^{u}	0.75^{a}	
Gypsum	0.259^{b}	78^{b}	0.25^{h}	0.903^{b}	On a smooth plate
Hemp (fiber)	0.323^{u}	93^{u}			
Ice: 32°F	0.487^{t}	57.5^{b}	1.3^{b}	0.95^{*}	
−4°F	0.465^{t}		1.41^{*}		
Iron: Cast	0.12^{v} (212)	450^{h}	27.6^{h} (129)	0.435^{h}	Freshly turned
Wrought		485^{h}	34.9^{b}	0.94^{h}	Dull, oxidized
Lead	0.0309^{u}	707^{a}	20.1^{k}	0.28^{a}	Gray, oxidized
Leather (sole)		62.4^{h}	0.092^{b}		
Limestone	0.217^{h}	103^{h}	0.54^{b}	0.36^{*} to 0.90	At 145 to 380°F
Linen			0.05^{b}		
Litharge (lead monoxide)	0.055^{b}	490^{p}			
Magnesia: Powdered	0.234^{h} (212)	49.7^{h}	0.35^{h} (117)		
Light carbonate		13^{h}	0.034^{b}		
Magnesite brick	0.222^{h} (212)	158^{h}	2.2^{b} (400)		
Magnesium	0.241^{h}	108^{a}	91^{u}	0.55^{n}	Oxidized
Marble	0.21^{b}	162^{h}	1.5^{h}	0.931^{h}	Light gray, polished
Nickel, polished	0.105^{u}	555^{u}	34.4^{u}	0.045^{n}	Electroplated
Paints: White lacquer				0.80^{a}	
White enamel				0.91^{n}	On rough plate
Black lacquer				0.80^{n}	
Black shellac		63^{u}	0.15^{u}	0.91^{n}	"Matte" finish
Flat black lacquer				0.96^{e}	
Aluminum lacquer				0.39^{n}	On rough plate

*Data source unknown.

Notes: 1. Values are for room temperature unless otherwise noted in parentheses.

2. Superscript letters indicate data source from the section on References.

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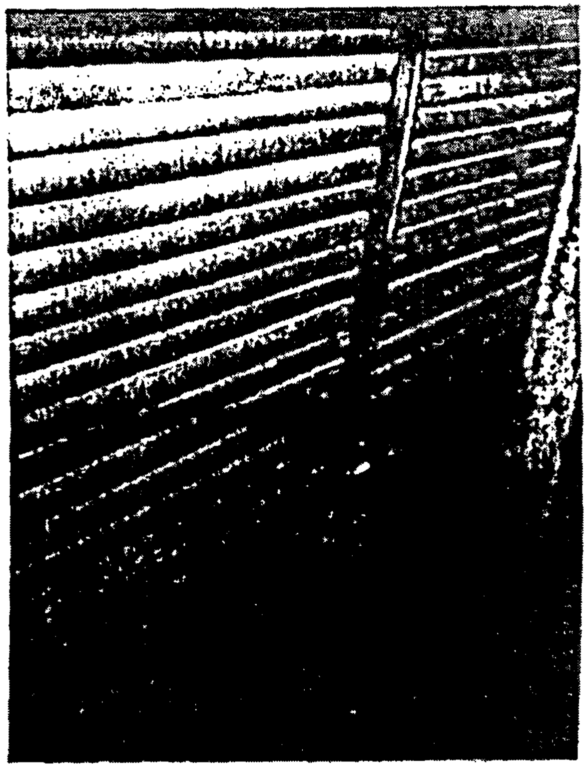
Attachment B to
Proto-Power Calculation
97-198
Revision A

LA SALLE COUNTY STATION
HEAT EXCHANGER
(WATER TO AIR)
DATABASE

EQUIPMENT NUMBER/ NAME	INSPECT DATE	BASE	PHOT	PHOTO STORAGE LOCATION	GENERAL APPEARANCE	TUBE CONDITION	FINS CONDITION	DEFECTS	CORRECTIVE ACTIONS RECOMMENDED	CORRECTIVE ACTIONS ACTUAL
1VY04C LPCS/RCIC COOLER	09/22/92	N	Y	BTN/XAPSHOT HX#1	VERY CLEAN. NO DEBRIS.	NO DAMAGE NOTICED.	CLEAN, NO DEBRIS. A FEW FINS BENT.	NONE	NONE NEEDED	N/A

1VY04C INLET SIDE 9/22/92



1VY04C OUTLET SIDE 9/22/92

Attachment C to
Proto-Power Calculation
97-198
Revision A

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	33,546.00 acfm	118.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	CF-9.05-3/4J A
	j = EXP[-2.3333 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	118.00
Air Flow (acfm)	33,546.00
Tube Inlet Temp (°F)	105.00
Air Inlet Temp (°F)	150.0
Inlet Relative Humidity (%)	0.00
Inlet Wet Bulb Temp (°F)	92.00
Atmospheric Pressure	14.315

ComEd -- LaSalle

Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

Initial Benchmark Case -- Standard Coil

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.84	58,613.21
Inlet Temperature (°F)	150.00	105.00
Outlet Temperature (°F)	128.93	116.13
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft^{3})		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft^{2}·°F)	
j Factor	
Air-Side ho (BTU/hr·ft^{2}·°F)	
Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00024732
Overall Fouling (hr·ft^{2}·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^{2}·°F)	
Effective Area (ft^{2})	2,952.05
LMTD	
Total Heat Transferred (BTU/hr)	651,158
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	651,158
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.84	58,613.21
Inlet Temperature (°F)	150.00	110.48
Outlet Temperature (°F)	143.83	117.00
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	146.92	113.74
Skin Temperature (°F)	124.56	118.70
Velocity ***	6,255.18	2.17
Reynold's Number	2,270	14,855
Prandtl Number	0.7252	3.8824
Bulk Visc (lbm/ft·hr)	0.0492	1.4299
Skin Visc (lbm/ft·hr)		1.3631
Density (lbm/ft^{3})	0.0620	61.8061
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0163	0.3679

Tube-Side hi (BTU/hr·ft^{2}·°F)	778.41
j Factor	0.0068
Air-Side ho (BTU/hr·ft^{2}·°F)	12.64
Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00024732
Overall Fouling (hr·ft^{2}·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^{2}·°F)	7.83
Effective Area (ft^{2})	738.01
LMTD	32.98
Total Heat Transferred (BTU/hr)	190,706
Surface Effectiveness (Eta)	0.9200
Sensible Heat Transferred (BTU/hr)	190,706
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^{2}), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.84	58,613.21	Tube-Side hi (BTU/hr·ft^2·°F)	772.57
Inlet Temperature (°F)	143.83	109.65	j Factor	0.0068
Outlet Temperature (°F)	138.51	115.27	Air-Side ho (BTU/hr·ft^2·°F)	12.60
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	141.17	112.46		
Skin Temperature (°F)	121.83	116.77	U Overall (BTU/hr·ft^2·°F)	7.81
Velocity ***	6,255.18	2.17	Effective Area (ft^2)	738.01
Reynold's Number	2,286	14,669	LMTD	28.54
Prandtl Number	0.7257	3.9365	Total Heat Transferred (BTU/hr)	164,550
Bulk Visc (lbm/ft·hr)	0.0488	1.4481		
Skin Visc (lbm/ft·hr)		1.3885	Surface Effectiveness (Eta)	0.9203
Density (lbm/ft^3)	0.0626	61.8248	Sensible Heat Transferred (BTU/hr)	164,550
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0162	0.3674	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.84	58,613.21	Tube-Side hi (BTU/hr·ft^2·°F)	753.48
Inlet Temperature (°F)	138.51	105.00	j Factor	0.0068
Outlet Temperature (°F)	133.31	110.48	Air-Side ho (BTU/hr·ft^2·°F)	12.57
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	135.91	107.74		
Skin Temperature (°F)	116.99	112.05	U Overall (BTU/hr·ft^2·°F)	7.77
Velocity ***	6,255.18	2.17	Effective Area (ft^2)	738.01
Reynold's Number	2,302	13,990	LMTD	28.01
Prandtl Number	0.7262	4.1470	Total Heat Transferred (BTU/hr)	160,581
Bulk Visc (lbm/ft·hr)	0.0485	1.5184		
Skin Visc (lbm/ft·hr)		1.4539	Surface Effectiveness (Eta)	0.9204
Density (lbm/ft^3)	0.0631	61.8916	Sensible Heat Transferred (BTU/hr)	160,581
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0160	0.3657	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	123,544.84	58,613.21
Inlet Temperature (°F)	133.31	105.02
Outlet Temperature (°F)	128.93	109.65
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	131.12	107.34
Skin Temperature (°F)	115.14	110.98
Velocity ***	6,255.18	2.17
Reynold's Number	2,316	13,932
Prandtl Number	0.7266	4.1658
Bulk Visc (lbm/ft·hr)	0.0482	1.5246
Skin Visc (lbm/ft·hr)		1.4695
Density (lbm/ft³)	0.0636	61.8972
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3656

Tube-Side hi (BTU/hr·ft²·°F)	751.14
j Factor	0.0067
Air-Side ho (BTU/hr·ft²·°F)	12.53
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	7.75
Effective Area (ft²)	738.01
LMTD	23.65
Total Heat Transferred (BTU/hr)	135,321
Surface Effectiveness (Eta)	0.9206
Sensible Heat Transferred (BTU/hr)	135,321
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Moist Air Properties -- Given Dry Bulb and Specific Humidity*

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	128.93	°F	
Specific Humidity:	W =	0.020337508		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.453253232	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86174677	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.063563747	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001292728	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.064856475	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	2.162352424	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	20.96111746	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Back Coil Inlet Conditions (Initial Benchmark)
[See Attachment H]

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Data Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
Initial Benchmark Case -- Standard Coil

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	32,483.00 acfm	82.00 gpm
Inlet Dry Bulb Temp	°F	105.00 °F
Inlet Wet Bulb Temp	°F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	CF-9.05-3/4J A j = EXP[-2.3333 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

Initial Benchmark Case -- Standard Coil

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	82.00
Air Flow (acfm)	32,386.60
Tube Inlet Temp (°F)	105.00
Air Inlet Temp (°F)	128.9
Inlet Relative Humidity (%)	20.96
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

← Adjusted to match Front Coil mass flow

08:54:10 **PROTO-HX 3.01 by Proto-Power Corporation (SN#PHX-0000)** 07/10/98

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

Initial Benchmark Case -- Standard Coil

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	128.93	105.00
Outlet Temperature (°F)	113.67	116.61
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	5,904.10
LMTD	
Total Heat Transferred (BTU/hr)	471,786
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	471,786
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	128.93	113.84
Outlet Temperature (°F)	126.66	117.29
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	127.79	115.56
Skin Temperature (°F)	120.17	118.00
Velocity ***	6,255.18	1.51
Reynold's Number	1,745	10,508
Prandtl Number	0.7268	3.8074
Bulk Visc (lbm/ft·hr)	0.0480	1.4048
Skin Visc (lbm/ft·hr)		1.3722
Density (lbm/ft³)	0.0638	61.7791
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3685

Tube-Side hi (BTU/hr·ft²·°F)	585.29
j Factor	0.0074
Air-Side ho (BTU/hr·ft²·°F)	13.81
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	7.86
Effective Area (ft²)	738.01
LMTD	12.12
Total Heat Transferred (BTU/hr)	70,311
Surface Effectiveness (Eta)	0.9134
Sensible Heat Transferred (BTU/hr)	70,311
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	126.66	112.74
Outlet Temperature (°F)	124.56	115.92
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	125.61	114.33
Skin Temperature (°F)	118.59	116.59
Velocity ***	6,255.18	1.51
Reynold's Number	1,750	10,383
Prandtl Number	0.7270	3.8578
Bulk Visc (lbm/ft·hr)	0.0478	1.4217
Skin Visc (lbm/ft·hr)		1.3909
Density (lbm/ft³)	0.0641	61.7974
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3681

Tube-Side hi (BTU/hr·ft²·°F)	581.45
j Factor	0.0074
Air-Side ho (BTU/hr·ft²·°F)	13.80
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	7.85
Effective Area (ft²)	738.01
LMTD	11.17
Total Heat Transferred (BTU/hr)	64,711
Surface Effectiveness (Eta)	0.9135
Sensible Heat Transferred (BTU/hr)	64,711
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	124.56	110.67
Outlet Temperature (°F)	122.48	113.84
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	123.52	112.25
Skin Temperature (°F)	116.52	114.53
Velocity ***	6,255.18	1.51
Reynold's Number	1,754	10,172
Prandtl Number	0.7272	3.9455
Bulk Visc (lbm/ft·hr)	0.0477	1.4511
Skin Visc (lbm/ft·hr)		1.4190
Density (lbm/ft³)	0.0643	61.8278
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3673

Tube-Side hi (BTU/hr·ft²·°F)	575.19
j Factor	0.0074
Air-Side ho (BTU/hr·ft²·°F)	13.78
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	7.83
Effective Area (ft²)	738.01
LMTD	11.17
Total Heat Transferred (BTU/hr)	64,486
Surface Effectiveness (Eta)	0.9136
Sensible Heat Transferred (BTU/hr)	64,486
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	122.48	109.87
Outlet Temperature (°F)	120.59	112.74
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	121.53	111.30
Skin Temperature (°F)	115.18	113.38
Velocity ***	6,255.18	1.51
Reynold's Number	1,759	10,077
Prandtl Number	0.7273	3.9864
Bulk Visc (lbm/ft·hr)	0.0476	1.4648
Skin Visc (lbm/ft·hr)		1.4350
Density (lbm/ft³)	0.0645	61.8414
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3670

Tube-Side hi (BTU/hr·ft²·°F)	572.18
j Factor	0.0074
Air-Side ho (BTU/hr·ft²·°F)	13.77
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	7.81
Effective Area (ft²)	738.01
LMTD	10.13
Total Heat Transferred (BTU/hr)	58,422
Surface Effectiveness (Eta)	0.9137
Sensible Heat Transferred (BTU/hr)	58,422
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	120.59	107.75
Outlet Temperature (°F)	118.66	110.67
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	119.63	109.21
Skin Temperature (°F)	113.17	111.34
Velocity ***	6,255.18	1.51
Reynold's Number	1,764	9,867
Prandtl Number	0.7274	4.0797
Bulk Visc (lbm/ft·hr)	0.0475	1.4959
Skin Visc (lbm/ft·hr)		1.4643
Density (lbm/ft³)	0.0647	61.8712
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3663

Tube-Side hi (BTU/hr·ft²·°F)	565.78
j Factor	0.0074
Air-Side ho (BTU/hr·ft²·°F)	13.76
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	7.79
Effective Area (ft²)	738.01
LMTD	10.32
Total Heat Transferred (BTU/hr)	59,363
Surface Effectiveness (Eta)	0.9137
Sensible Heat Transferred (BTU/hr)	59,363
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.82	40,731.22	Tube-Side hi (BTU/hr·ft²·°F)	563.58
Inlet Temperature (°F)	118.66	107.28	j Factor	0.0074
Outlet Temperature (°F)	116.96	109.87	Air-Side ho (BTU/hr·ft²·°F)	13.74
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	117.81	108.58		
Skin Temperature (°F)	112.09	110.47	U Overall (BTU/hr·ft²·°F)	7.78
Velocity ***	6,255.18	1.51	Effective Area (ft²)	738.01
Reynold's Number	1,768	9,805	LMTD	9.15
Prandtl Number	0.7276	4.1083	Total Heat Transferred (BTU/hr)	52,562
Bulk Visc (lbm/ft·hr)	0.0473	1.5055		
Skin Visc (lbm/ft·hr)		1.4770	Surface Effectiveness (Eta)	0.9138
Density (lbm/ft³)	0.0649	61.8800	Sensible Heat Transferred (BTU/hr)	52,562
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3660	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.82	40,731.22	Tube-Side hi (BTU/hr·ft²·°F)	556.37
Inlet Temperature (°F)	116.96	105.05	j Factor	0.0074
Outlet Temperature (°F)	115.19	107.75	Air-Side ho (BTU/hr·ft²·°F)	13.73
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	116.08	106.40		
Skin Temperature (°F)	110.09	108.40	U Overall (BTU/hr·ft²·°F)	7.76
Velocity ***	6,255.18	1.51	Effective Area (ft²)	738.01
Reynold's Number	1,772	9,589	LMTD	9.59
Prandtl Number	0.7277	4.2102	Total Heat Transferred (BTU/hr)	54,903
Bulk Visc (lbm/ft·hr)	0.0472	1.5394		
Skin Visc (lbm/ft·hr)		1.5082	Surface Effectiveness (Eta)	0.9139
Density (lbm/ft³)	0.0651	61.9101	Sensible Heat Transferred (BTU/hr)	54,903
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3652	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

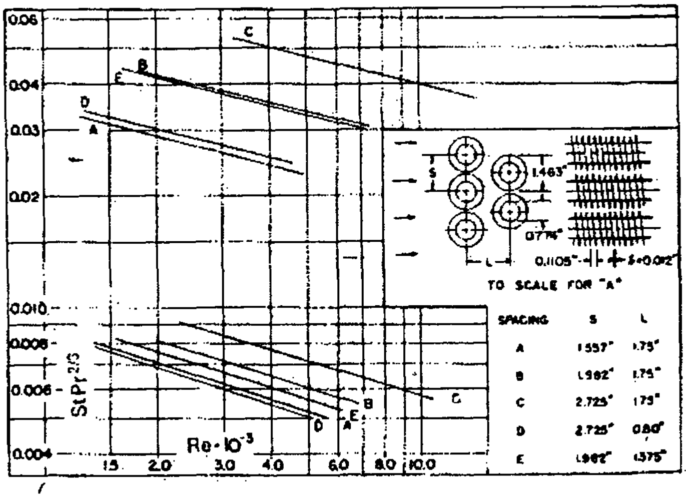
	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	115.19	104.97
Outlet Temperature (°F)	113.67	107.28
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	114.43	106.13
Skin Temperature (°F)	109.30	107.85
Velocity ***	6,255.18	1.51
Reynold's Number	1,776	9,562
Prandtl Number	0.7278	4.2230
Bulk Visc (lbm/ft·hr)	0.0471	1.5436
Skin Visc (lbm/ft·hr)		1.5167
Density (lbm/ft^3)	0.0653	61.9137
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3651

Tube-Side hi (BTU/hr·ft^2·°F)	555.21
j Factor	0.0074
Air-Side ho (BTU/hr·ft^2·°F)	13.72
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	7.75
Effective Area (ft^2)	738.01
LMTD	8.22
Total Heat Transferred (BTU/hr)	47,029
Surface Effectiveness (Eta)	0.9140
Sensible Heat Transferred (BTU/hr)	47,029
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment D to
Proto-Power Calculation
97-198
Revision A

Fig. 10-89 Finned circular tubes, surface CF-9.05-3/4J. *(Data of Jameson.)*



SPACING	S	L
A	1.557"	1.75"
B	1.982"	1.75"
C	2.725"	1.75"
D	2.725"	0.80"
E	1.982"	1.375"

Tube outside diameter = 0.774 in = 19.66×10^{-3} m
Fin pitch = 9.05 per in = 356 per m
Fin thickness = 0.012 in = 0.305×10^{-3} m
Fin area/total area = 0.835

	A	*B*	*C*	*D*	*E*
Flow passage hydraulic diameter, $4r_h$ =	0.01681	0.02685	0.0445	0.01587	0.02108 ft
=	5.131×10^{-3}	8.179×10^{-3}	13.59×10^{-3}	4.846×10^{-3}	6.426×10^{-3} m

Free flow area/frontal area, σ =	0.455	0.572	0.688	0.537	0.572
Heat transfer area/total volume, α =	108	85.1	61.9	135	108 ft^2/ft^3
=	354	279	203	443	354 m^2/m^3

Note: Minimum free-flow area in all cases occurs in the spaces transverse to the flow, except for *D*, in which the minimum area is in the diagonals.

Attachment E to
Proto-Power Calculation
97-198
Revision A

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	33,546.00 acfm	118.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle VY Cooler 04A
	j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date
Air Flow (acfm)
Air Dry Bulb Temp In (°F)
Air Dry Bulb Temp Out (°F)
Relative Humidity In (%)
Relative Humidity Out (%)
Wet Bulb Temp In (°F)
Wet Bulb Temp Out (°F)
Atmospheric Pressure
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)
Condensate Temperature (°F)

Extrapolation Data

Tube Flow (gpm)	118.00
Air Flow (acfm)	33,546.00
Tube Inlet Temp (°F)	105.00
Air Inlet Temp (°F)	150.0
Inlet Relative Humidity (%)	0.00
Inlet Wet Bulb Temp (°F)	92.00
Atmospheric Pressure	14.315

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils
Final Benchmark Case -- Custom Coil

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.84	58,613.21	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	150.00	105.00	j Factor	
Outlet Temperature (°F)	125.78	117.75	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	2,952.05
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	748,549
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	748,549
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.84	58,613.21	Tube-Side hi (BTU/hr·ft²·°F)	784.81
Inlet Temperature (°F)	150.00	111.22	j Factor	0.0103
Outlet Temperature (°F)	142.66	118.97	Air-Side ho (BTU/hr·ft²·°F)	19.09
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	146.33	115.10		
Skin Temperature (°F)	127.97	120.97	U Overall (BTU/hr·ft²·°F)	9.94
Velocity ***	6,255.18	2.17	Effective Area (ft²)	738.01
Reynold's Number	2,272	15,053	LMTD	30.94
Prandtl Number	0.7253	3.8263	Total Heat Transferred (BTU/hr)	226,898
Bulk Visc (lbm/ft·hr)	0.0491	1.4111		
Skin Visc (lbm/ft·hr)		1.3342	Surface Effectiveness (Eta)	0.8852
Density (lbm/ft³)	0.0621	61.7861	Sensible Heat Transferred (BTU/hr)	226,898
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3684	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.84	58,613.21	Tube-Side hi (BTU/hr·ft^2·°F)	776.58
Inlet Temperature (°F)	142.66	110.03	j Factor	0.0102
Outlet Temperature (°F)	136.50	116.53	Air-Side ho (BTU/hr·ft^2·°F)	19.02
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	139.58	113.28		
Skin Temperature (°F)	124.13	118.26	U Overall (BTU/hr·ft^2·°F)	9.90
Velocity ***	6,255.18	2.17	Effective Area (ft^2)	738.01
Reynold's Number	2,291	14,788	LMTD	26.06
Prandtl Number	0.7259	3.9016	Total Heat Transferred (BTU/hr)	190,348
Bulk Visc (lbm/ft·hr)	0.0487	1.4364		
Skin Visc (lbm/ft·hr)		1.3688	Surface Effectiveness (Eta)	0.8856
Density (lbm/ft^3)	0.0628	61.8128	Sensible Heat Transferred (BTU/hr)	190,348
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0161	0.3677	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.84	58,613.21	Tube-Side hi (BTU/hr·ft^2·°F)	755.57
Inlet Temperature (°F)	136.50	104.97	j Factor	0.0102
Outlet Temperature (°F)	130.58	111.22	Air-Side ho (BTU/hr·ft^2·°F)	18.97
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	133.54	108.10		
Skin Temperature (°F)	118.65	113.02	U Overall (BTU/hr·ft^2·°F)	9.83
Velocity ***	6,255.18	2.17	Effective Area (ft^2)	738.01
Reynold's Number	2,309	14,041	LMTD	25.21
Prandtl Number	0.7264	4.1303	Total Heat Transferred (BTU/hr)	182,919
Bulk Visc (lbm/ft·hr)	0.0483	1.5128		
Skin Visc (lbm/ft·hr)		1.4401	Surface Effectiveness (Eta)	0.8859
Density (lbm/ft^3)	0.0634	61.8867	Sensible Heat Transferred (BTU/hr)	182,919
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0160	0.3658	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	123,544.84	58,613.21
Inlet Temperature (°F)	130.58	104.96
Outlet Temperature (°F)	125.78	110.03
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	128.18	107.50
Skin Temperature (°F)	116.08	111.50
Velocity ***	6,255.18	2.17
Reynold's Number	2,325	13,955
Prandtl Number	0.7268	4.1584
Bulk Visc (lbm/ft·hr)	0.0480	1.5221
Skin Visc (lbm/ft·hr)		1.4619
Density (lbm/ft^3)	0.0639	61.8950
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3656

Tube-Side hi (BTU/hr·ft^2·°F)	752.17
j Factor	0.0102
Air-Side ho (BTU/hr·ft^2·°F)	18.91
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	9.81
Effective Area (ft^2)	738.01
LMTD	20.50
Total Heat Transferred (BTU/hr)	148,385
Surface Effectiveness (Eta)	0.8861
Sensible Heat Transferred (BTU/hr)	148,385
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	125.78	°F	
Specific Humidity:	W =	0.020337508		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.453253232	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86174677	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.06390575	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001299684	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.065205434	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.986075574	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	22.82155007	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Back Coil Inlet Conditions (Final Benchmark - Custom Coil)
[See Attachment H]

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	32,483.00 acfm	82.00 gpm
Inlet Dry Bulb Temp	°F	105.00 °F
Inlet Wet Bulb Temp	°F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY04A ← j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	108.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date
Air Flow (acfm)
Air Dry Bulb Temp In (°F)
Air Dry Bulb Temp Out (°F)
Relative Humidity In (%)
Relative Humidity Out (%)
Wet Bulb Temp In (°F)
Wet Bulb Temp Out (°F)
Atmospheric Pressure
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)
Condensate Temperature (°F)

Extrapolation Data

Tube Flow (gpm)	82.00
Air Flow (acfm)	32,213.26
Tube Inlet Temp (°F)	105.00
Air Inlet Temp (°F)	125.8
Inlet Relative Humidity (%)	22.82
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

← Adjusted to match Front Coil mass flow

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

Final Benchmark Case -- Custom Coil

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.82	40,731.22	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	125.78	105.00	j Factor	
Outlet Temperature (°F)	111.36	115.94	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	5,904.10
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	445,586
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	445,586
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.82	40,731.22	Tube-Side hi (BTU/hr·ft²·°F)	583.44
Inlet Temperature (°F)	125.78	113.27	j Factor	0.0112
Outlet Temperature (°F)	123.56	116.65	Air-Side ho (BTU/hr·ft²·°F)	20.84
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	124.67	114.96		
Skin Temperature (°F)	119.49	117.36	U Overall (BTU/hr·ft²·°F)	9.73
Velocity ***	6,255.18	1.51	Effective Area (ft²)	738.01
Reynold's Number	1,752	10,446	LMTD	9.57
Prandtl Number	0.7271	3.8320	Total Heat Transferred (BTU/hr)	68,767
Bulk Visc (lbm/ft·hr)	0.0478	1.4130		
Skin Visc (lbm/ft·hr)		1.3806	Surface Effectiveness (Eta)	0.8764
Density (lbm/ft³)	0.0642	61.7882	Sensible Heat Transferred (BTU/hr)	68,767
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0158	0.3683	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	123.56	112.16
Outlet Temperature (°F)	121.53	115.23
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	122.54	113.69
Skin Temperature (°F)	117.83	115.90
Velocity ***	6,255.18	1.51
Reynold's Number	1,757	10,318
Prandtl Number	0.7272	3.8843
Bulk Visc (lbm/ft·hr)	0.0476	1.4306
Skin Visc (lbm/ft·hr)		1.4002
Density (lbm/ft³)	0.0644	61.8068
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3679

Tube-Side hi (BTU/hr·ft²·°F)	579.49
j Factor	0.0112
Air-Side ho (BTU/hr·ft²·°F)	20.82
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	9.71
Effective Area (ft²)	738.01
LMTD	8.73
Total Heat Transferred (BTU/hr)	62,535
Surface Effectiveness (Eta)	0.8765
Sensible Heat Transferred (BTU/hr)	62,535
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	121.53	110.22
Outlet Temperature (°F)	119.53	113.27
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	120.53	111.75
Skin Temperature (°F)	115.87	113.95
Velocity ***	6,255.18	1.51
Reynold's Number	1,761	10,122
Prandtl Number	0.7274	3.9672
Bulk Visc (lbm/ft·hr)	0.0475	1.4584
Skin Visc (lbm/ft·hr)		1.4270
Density (lbm/ft³)	0.0646	61.8351
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3672

Tube-Side hi (BTU/hr·ft²·°F)	573.61
j Factor	0.0112
Air-Side ho (BTU/hr·ft²·°F)	20.80
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	9.68
Effective Area (ft²)	738.01
LMTD	8.66
Total Heat Transferred (BTU/hr)	61,900
Surface Effectiveness (Eta)	0.8766
Sensible Heat Transferred (BTU/hr)	61,900
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.82	40,731.22	Tube-Side hi (BTU/hr·ft^2·°F)	570.58
Inlet Temperature (°F)	119.53	109.45	j Factor	0.0112
Outlet Temperature (°F)	117.75	112.16	Air-Side ho (BTU/hr·ft^2·°F)	20.78
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	118.64	110.80		
Skin Temperature (°F)	114.48	112.77	U Overall (BTU/hr·ft^2·°F)	9.66
Velocity ***	6,255.18	1.51	Effective Area (ft^2)	738.01
Reynold's Number	1,766	10,027	LMTD	7.73
Prandtl Number	0.7275	4.0084	Total Heat Transferred (BTU/hr)	55,111
Bulk Visc (lbm/ft·hr)	0.0474	1.4721		
Skin Visc (lbm/ft·hr)		1.4436	Surface Effectiveness (Eta)	0.8767
Density (lbm/ft^3)	0.0648	61.8486	Sensible Heat Transferred (BTU/hr)	55,111
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0157	0.3668	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.82	40,731.22	Tube-Side hi (BTU/hr·ft^2·°F)	564.55
Inlet Temperature (°F)	117.75	107.47	j Factor	0.0112
Outlet Temperature (°F)	115.93	110.22	Air-Side ho (BTU/hr·ft^2·°F)	20.76
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	116.84	108.85		
Skin Temperature (°F)	112.61	110.87	U Overall (BTU/hr·ft^2·°F)	9.63
Velocity ***	6,255.18	1.51	Effective Area (ft^2)	738.01
Reynold's Number	1,770	9,832	LMTD	7.88
Prandtl Number	0.7276	4.0960	Total Heat Transferred (BTU/hr)	56,053
Bulk Visc (lbm/ft·hr)	0.0473	1.5014		
Skin Visc (lbm/ft·hr)		1.4711	Surface Effectiveness (Eta)	0.8768
Density (lbm/ft^3)	0.0650	61.8762	Sensible Heat Transferred (BTU/hr)	56,053
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3661	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	**Tube-Side**		
Mass Flow (lbm/hr)	123,544.82	40,731.22	Tube-Side hi (BTU/hr·ft^2·°F)	562.44
Inlet Temperature (°F)	115.93	107.08	j Factor	0.0112
Outlet Temperature (°F)	114.37	109.45	Air-Side ho (BTU/hr·ft^2·°F)	20.74
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	115.15	108.26		
Skin Temperature (°F)	111.51	110.01	U Overall (BTU/hr·ft^2·°F)	9.62
Velocity ***	6,255.18	1.51	Effective Area (ft^2)	738.01
Reynold's Number	1,774	9,774	LMTD	6.80
Prandtl Number	0.7277	4.1228	Total Heat Transferred (BTU/hr)	48,255
Bulk Visc (lbm/ft·hr)	0.0472	1.5103		
Skin Visc (lbm/ft·hr)		1.4838	Surface Effectiveness (Eta)	0.8769
Density (lbm/ft^3)	0.0652	61.8844	Sensible Heat Transferred (BTU/hr)	48,255
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3659	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	**Tube-Side**		
Mass Flow (lbm/hr)	123,544.82	40,731.22	Tube-Side hi (BTU/hr·ft^2·°F)	555.62
Inlet Temperature (°F)	114.37	104.95	j Factor	0.0112
Outlet Temperature (°F)	112.72	107.47	Air-Side ho (BTU/hr·ft^2·°F)	20.72
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	113.54	106.21		
Skin Temperature (°F)	109.67	108.09	U Overall (BTU/hr·ft^2·°F)	9.59
Velocity ***	6,255.18	1.51	Effective Area (ft^2)	738.01
Reynold's Number	1,778	9,571	LMTD	7.23
Prandtl Number	0.7278	4.2191	Total Heat Transferred (BTU/hr)	51,182
Bulk Visc (lbm/ft·hr)	0.0471	1.5423		
Skin Visc (lbm/ft·hr)		1.5129	Surface Effectiveness (Eta)	0.8770
Density (lbm/ft^3)	0.0654	61.9126	Sensible Heat Transferred (BTU/hr)	51,182
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0155	0.3651	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	112.72	105.02
Outlet Temperature (°F)	111.36	107.08
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	112.04	106.05
Skin Temperature (°F)	108.88	107.59
Velocity ***	6,255.18	1.51
Reynold's Number	1,782	9,555
Prandtl Number	0.7279	4.2269
Bulk Visc (lbm/ft·hr)	0.0470	1.5449
Skin Visc (lbm/ft·hr)		1.5207
Density (lbm/ft³)	0.0655	61.9148
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0155	0.3651

Tube-Side hi (BTU/hr·ft²·°F)	554.79
j Factor	0.0111
Air-Side ho (BTU/hr·ft²·°F)	20.70
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	9.58
Effective Area (ft²)	738.01
LMTD	5.91
Total Heat Transferred (BTU/hr)	41,784
Surface Effectiveness (Eta)	0.8771
Sensible Heat Transferred (BTU/hr)	41,784
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Data Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils
Final Benchmark -- Effective Length

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	33,546.00 acfm	118.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle VY Cooler 04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

Final Benchmark -- Effective Length

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	118.00
Air Flow (acfm)	33,546.00
Tube Inlet Temp (°F)	105.00
Air Inlet Temp (°F)	150.0
Inlet Relative Humidity (%)	0.00
Inlet Wet Bulb Temp (°F)	92.00
Atmospheric Pressure	14.315

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.84	58,613.21
Inlet Temperature (°F)	150.00	105.00
Outlet Temperature (°F)	126.03	117.62
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft^{3})		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft^{2}·°F)	
j Factor	
Air-Side ho (BTU/hr·ft^{2}·°F)	
Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00024732
Overall Fouling (hr·ft^{2}·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^{2}·°F)	
Effective Area (ft^{2})	2,870.05
LMTD	
Total Heat Transferred (BTU/hr)	740,828
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	740,828
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.84	58,613.21
Inlet Temperature (°F)	150.00	111.15
Outlet Temperature (°F)	142.75	118.80
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	146.38	114.97
Skin Temperature (°F)	128.04	120.94
Velocity ***	6,433.90	2.17
Reynold's Number	2,336	15,035
Prandtl Number	0.7253	3.8314
Bulk Visc (lbm/ft·hr)	0.0491	1.4128
Skin Visc (lbm/ft·hr)		1.3346
Density (lbm/ft^{3})	0.0621	61.7879
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0163	0.3683

Tube-Side hi (BTU/hr·ft^{2}·°F)	784.40
j Factor	0.0102
Air-Side ho (BTU/hr·ft^{2}·°F)	19.45
Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00024732
Overall Fouling (hr·ft^{2}·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^{2}·°F)	10.03
Effective Area (ft^{2})	717.51
LMTD	31.12
Total Heat Transferred (BTU/hr)	224,017
Surface Effectiveness (Eta)	0.8834
Sensible Heat Transferred (BTU/hr)	224,017
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^{2}), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.84	58,613.21	Tube-Side hi (BTU/hr·ft^{2}·°F)	776.46
Inlet Temperature (°F)	142.75	110.02	j Factor	0.0101
Outlet Temperature (°F)	136.66	116.44	Air-Side ho (BTU/hr·ft^{2}·°F)	19.38
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^{2}·°F/BTU)	0.02228812
Average Temp (°F)	139.71	113.23		
Skin Temperature (°F)	124.26	118.29	U Overall (BTU/hr·ft^{2}·°F)	9.99
Velocity ***	6,433.90	2.17	Effective Area (ft^{2})	717.51
Reynold's Number	2,356	14,781	LMTD	26.24
Prandtl Number	0.7259	3.9038	Total Heat Transferred (BTU/hr)	188,187
Bulk Visc (lbm/ft·hr)	0.0487	1.4371		
Skin Visc (lbm/ft·hr)		1.3684	Surface Effectiveness (Eta)	0.8837
Density (lbm/ft^{3})	0.0628	61.8136	Sensible Heat Transferred (BTU/hr)	188,187
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0161	0.3677	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.84	58,613.21	Tube-Side hi (BTU/hr·ft^{2}·°F)	755.47
Inlet Temperature (°F)	136.66	104.95	j Factor	0.0101
Outlet Temperature (°F)	130.80	111.15	Air-Side ho (BTU/hr·ft^{2}·°F)	19.32
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^{2}·°F/BTU)	0.02228812
Average Temp (°F)	133.73	108.05		
Skin Temperature (°F)	118.81	113.06	U Overall (BTU/hr·ft^{2}·°F)	9.93
Velocity ***	6,433.90	2.17	Effective Area (ft^{2})	717.51
Reynold's Number	2,374	14,034	LMTD	25.46
Prandtl Number	0.7264	4.1326	Total Heat Transferred (BTU/hr)	181,300
Bulk Visc (lbm/ft·hr)	0.0483	1.5136		
Skin Visc (lbm/ft·hr)		1.4395	Surface Effectiveness (Eta)	0.8841
Density (lbm/ft^{3})	0.0634	61.8874	Sensible Heat Transferred (BTU/hr)	181,300
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0160	0.3658	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^{2}), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.84	58,613.21
Inlet Temperature (°F)	130.80	104.98
Outlet Temperature (°F)	126.03	110.02
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	128.42	107.50
Skin Temperature (°F)	116.26	111.59
Velocity ***	6,433.90	2.17
Reynold's Number	2,391	13,956
Prandtl Number	0.7268	4.1582
Bulk Visc (lbm/ft·hr)	0.0480	1.5221
Skin Visc (lbm/ft·hr)		1.4606
Density (lbm/ft³)	0.0639	61.8950
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3656

Tube-Side hi (BTU/hr·ft²·°F)	752.27
j Factor	0.0101
Air-Side ho (BTU/hr·ft²·°F)	19.27
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	9.90
Effective Area (ft²)	717.51
LMTD	20.73
Total Heat Transferred (BTU/hr)	147,324
Surface Effectiveness (Eta)	0.8843
Sensible Heat Transferred (BTU/hr)	147,324
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	126.03	°F	
Specific Humidity:	W =	0.020337508		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.453253232	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86174677	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.063878473	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001299129	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.065177602	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.999601173	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	22.66718172	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Back Coil Inlet Conditions (Final Benchmark - Effective Length)
[See Attachment H]

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Data Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
Final Benchmark -- Effective Length

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	32,483.00 acfm	82.00 gpm
Inlet Dry Bulb Temp	°F	105.00 °F
Inlet Wet Bulb Temp	°F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000 ←
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	82.00
Air Flow (acfm)	32,227.22
Tube Inlet Temp (°F)	105.00
Air Inlet Temp (°F)	126.0
Inlet Relative Humidity (%)	22.67
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

← Adjusted to match Front Coil Mass Flow

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	126.03	105.00
Outlet Temperature (°F)	111.56	116.01
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft^3)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft^2·°F)	
j Factor	
Air-Side ho (BTU/hr·ft^2·°F)	
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	
Effective Area (ft^2)	5,740.10
LMTD	
Total Heat Transferred (BTU/hr)	447,161
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	447,161
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	126.03	113.35
Outlet Temperature (°F)	123.81	116.73
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	124.92	115.04
Skin Temperature (°F)	119.69	117.51
Velocity ***	6,433.90	1.51
Reynold's Number	1,801	10,455
Prandtl Number	0.7271	3.8287
Bulk Visc (lbm/ft·hr)	0.0478	1.4119
Skin Visc (lbm/ft·hr)		1.3787
Density (lbm/ft^3)	0.0641	61.7870
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3683

Tube-Side hi (BTU/hr·ft^2·°F)	583.74
j Factor	0.0111
Air-Side ho (BTU/hr·ft^2·°F)	21.23
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	9.82
Effective Area (ft^2)	717.51
LMTD	9.75
Total Heat Transferred (BTU/hr)	68,671
Surface Effectiveness (Eta)	0.8744
Sensible Heat Transferred (BTU/hr)	68,671
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	123.81	112.21
Outlet Temperature (°F)	121.78	115.29
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	122.79	113.75
Skin Temperature (°F)	118.02	116.02
Velocity ***	6,433.90	1.51
Reynold's Number	1,806	10,324
Prandtl Number	0.7272	3.8819
Bulk Visc (lbm/ft·hr)	0.0477	1.4298
Skin Visc (lbm/ft·hr)		1.3985
Density (lbm/ft^3)	0.0644	61.8059
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3679

Tube-Side hi (BTU/hr·ft^2·°F)	579.71
j Factor	0.0111
Air-Side ho (BTU/hr·ft^2·°F)	21.21
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	9.80
Effective Area (ft^2)	717.51
LMTD	8.92
Total Heat Transferred (BTU/hr)	62,709
Surface Effectiveness (Eta)	0.8745
Sensible Heat Transferred (BTU/hr)	62,709
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	121.78	110.31
Outlet Temperature (°F)	119.78	113.35
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	120.78	111.83
Skin Temperature (°F)	116.06	114.09
Velocity ***	6,433.90	1.51
Reynold's Number	1,811	10,130
Prandtl Number	0.7274	3.9636
Bulk Visc (lbm/ft·hr)	0.0475	1.4571
Skin Visc (lbm/ft·hr)		1.4250
Density (lbm/ft^3)	0.0646	61.8339
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0157	0.3672

Tube-Side hi (BTU/hr·ft^2·°F)	573.91
j Factor	0.0111
Air-Side ho (BTU/hr·ft^2·°F)	21.19
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	9.77
Effective Area (ft^2)	717.51
LMTD	8.83
Total Heat Transferred (BTU/hr)	61,878
Surface Effectiveness (Eta)	0.8747
Sensible Heat Transferred (BTU/hr)	61,878
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.82	40,731.22	Tube-Side hi (BTU/hr·ft²·°F)	570.77
Inlet Temperature (°F)	119.78	109.48	j Factor	0.0111
Outlet Temperature (°F)	117.98	112.21	Air-Side ho (BTU/hr·ft²·°F)	21.17
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	118.88	110.85		
Skin Temperature (°F)	114.65	112.89	U Overall (BTU/hr·ft²·°F)	9.75
Velocity ***	6,433.90	1.51	Effective Area (ft²)	717.51
Reynold's Number	1,816	10,031	LMTD	7.93
Prandtl Number	0.7275	4.0064	Total Heat Transferred (BTU/hr)	55,450
Bulk Visc (lbm/ft·hr)	0.0474	1.4715		
Skin Visc (lbm/ft·hr)		1.4420	Surface Effectiveness (Eta)	0.8748
Density (lbm/ft³)	0.0648	61.8480	Sensible Heat Transferred (BTU/hr)	55,450
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0157	0.3668	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.82	40,731.22	Tube-Side hi (BTU/hr·ft²·°F)	564.86
Inlet Temperature (°F)	117.98	107.55	j Factor	0.0111
Outlet Temperature (°F)	116.17	110.31	Air-Side ho (BTU/hr·ft²·°F)	21.15
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	117.08	108.93		
Skin Temperature (°F)	112.80	111.01	U Overall (BTU/hr·ft²·°F)	9.72
Velocity ***	6,433.90	1.51	Effective Area (ft²)	717.51
Reynold's Number	1,820	9,840	LMTD	8.04
Prandtl Number	0.7276	4.0922	Total Heat Transferred (BTU/hr)	56,057
Bulk Visc (lbm/ft·hr)	0.0473	1.5001		
Skin Visc (lbm/ft·hr)		1.4690	Surface Effectiveness (Eta)	0.8749
Density (lbm/ft³)	0.0650	61.8751	Sensible Heat Transferred (BTU/hr)	56,057
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3662	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.82	40,731.22	Tube-Side hi (BTU/hr·ft²·°F)	562.57
Inlet Temperature (°F)	116.17	107.09	j Factor	0.0111
Outlet Temperature (°F)	114.59	109.48	Air-Side ho (BTU/hr·ft²·°F)	21.13
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	115.38	108.29		
Skin Temperature (°F)	111.66	110.10	U Overall (BTU/hr·ft²·°F)	9.70
Velocity ***	6,433.90	1.51	Effective Area (ft²)	717.51
Reynold's Number	1,824	9,776	LMTD	7.00
Prandtl Number	0.7277	4.1217	Total Heat Transferred (BTU/hr)	48,761
Bulk Visc (lbm/ft·hr)	0.0472	1.5099		
Skin Visc (lbm/ft·hr)		1.4825	Surface Effectiveness (Eta)	0.8750
Density (lbm/ft³)	0.0652	61.8841	Sensible Heat Transferred (BTU/hr)	48,761
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0156	0.3659	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	123,544.82	40,731.22	Tube-Side hi (BTU/hr·ft²·°F)	555.96
Inlet Temperature (°F)	114.59	105.04	j Factor	0.0111
Outlet Temperature (°F)	112.94	107.55	Air-Side ho (BTU/hr·ft²·°F)	21.11
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	113.77	106.30		
Skin Temperature (°F)	109.85	108.23	U Overall (BTU/hr·ft²·°F)	9.67
Velocity ***	6,433.90	1.51	Effective Area (ft²)	717.51
Reynold's Number	1,828	9,579	LMTD	7.37
Prandtl Number	0.7278	4.2151	Total Heat Transferred (BTU/hr)	51,158
Bulk Visc (lbm/ft·hr)	0.0471	1.5410		
Skin Visc (lbm/ft·hr)		1.5109	Surface Effectiveness (Eta)	0.8750
Density (lbm/ft³)	0.0654	61.9115	Sensible Heat Transferred (BTU/hr)	51,158
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0155	0.3652	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	123,544.82	40,731.22
Inlet Temperature (°F)	112.94	105.00
Outlet Temperature (°F)	111.56	107.09
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	112.25	106.04
Skin Temperature (°F)	109.00	107.65
Velocity ***	6,433.90	1.51
Reynold's Number	1,832	9,554
Prandtl Number	0.7279	4.2271
Bulk Visc (lbm/ft·hr)	0.0470	1.5450
Skin Visc (lbm/ft·hr)		1.5198
Density (lbm/ft³)	0.0655	61.9149
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0155	0.3651

Tube-Side hi (BTU/hr·ft²·°F)	554.83
j Factor	0.0110
Air-Side ho (BTU/hr·ft²·°F)	21.09
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	9.66
Effective Area (ft²)	717.51
LMTD	6.13
Total Heat Transferred (BTU/hr)	42,478
Surface Effectiveness (Eta)	0.8751
Sensible Heat Transferred (BTU/hr)	42,478
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment F to
Proto-Power Calculation
97-198
Revision A

Data Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils
Thermal Margin Assessment (Clean)

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	33,546.00 acfm	118.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle VY Cooler 04A
	j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

Thermal Margin Assessment (Clean)

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Fouling Was Input by User ←

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	118.00
Air Flow (acfm)	30,718.70
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315
Input Fouling Factor	0.000000

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

Thermal Margin Assessment (Clean)

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,515.96	58,675.06
Inlet Temperature (°F)	148.00	100.00
Outlet Temperature (°F)	117.91	114.55
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	2,870.05
LMTD	
Total Heat Transferred (BTU/hr)	854,494
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	854,494
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,515.96	58,675.06
Inlet Temperature (°F)	148.00	106.88
Outlet Temperature (°F)	138.27	116.31
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	143.14	111.60
Skin Temperature (°F)	119.20	119.11
Velocity ***	5,911.62	2.18
Reynold's Number	2,155	14,559
Prandtl Number	0.7256	3.9736
Bulk Visc (lbm/ft·hr)	0.0489	1.4605
Skin Visc (lbm/ft·hr)		1.3578
Density (lbm/ft³)	0.0626	61.8372
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3671

Tube-Side hi (BTU/hr·ft²·°F)	773.05
j Factor	0.0104
Air-Side ho (BTU/hr·ft²·°F)	18.37
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	12.39
Effective Area (ft²)	717.51
LMTD	31.08
Total Heat Transferred (BTU/hr)	276,287
Surface Effectiveness (Eta)	0.8890
Sensible Heat Transferred (BTU/hr)	276,287
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,515.96	58,675.06
Inlet Temperature (°F)	138.27	105.24
Outlet Temperature (°F)	130.49	112.78
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	134.38	109.01
Skin Temperature (°F)	115.18	115.10
Velocity ***	5,911.62	2.17
Reynold's Number	2,180	14,186
Prandtl Number	0.7263	4.0886
Bulk Visc (lbm/ft·hr)	0.0484	1.4989
Skin Visc (lbm/ft·hr)		1.4110
Density (lbm/ft³)	0.0634	61.8740
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0160	0.3662

Tube-Side hi (BTU/hr·ft²·°F)	761.12
j Factor	0.0104
Air-Side ho (BTU/hr·ft²·°F)	18.28
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	12.31
Effective Area (ft²)	717.51
LMTD	25.01
Total Heat Transferred (BTU/hr)	220,818
Surface Effectiveness (Eta)	0.8894
Sensible Heat Transferred (BTU/hr)	220,818
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,515.96	58,675.06
Inlet Temperature (°F)	130.49	99.97
Outlet Temperature (°F)	123.36	106.88
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	126.93	103.43
Skin Temperature (°F)	109.26	109.19
Velocity ***	5,911.62	2.17
Reynold's Number	2,201	13,393
Prandtl Number	0.7269	4.3557
Bulk Visc (lbm/ft·hr)	0.0479	1.5876
Skin Visc (lbm/ft·hr)		1.4962
Density (lbm/ft³)	0.0642	61.9499
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0158	0.3641

Tube-Side hi (BTU/hr·ft²·°F)	738.07
j Factor	0.0104
Air-Side ho (BTU/hr·ft²·°F)	18.21
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	12.18
Effective Area (ft²)	717.51
LMTD	23.17
Total Heat Transferred (BTU/hr)	202,528
Surface Effectiveness (Eta)	0.8898
Sensible Heat Transferred (BTU/hr)	202,528
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	113,515.96	58,675.06
Inlet Temperature (°F)	123.36	99.96
Outlet Temperature (°F)	117.91	105.24
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	120.64	102.60
Skin Temperature (°F)	107.09	107.03
Velocity ***	5,911.62	2.17
Reynold's Number	2,219	13,277
Prandtl Number	0.7274	4.3977
Bulk Visc (lbm/ft·hr)	0.0475	1.6015
Skin Visc (lbm/ft·hr)		1.5293
Density (lbm/ft³)	0.0648	61.9608
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3638

Tube-Side hi (BTU/hr·ft²·°F)	733.30
j Factor	0.0103
Air-Side ho (BTU/hr·ft²·°F)	18.15
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	12.14
Effective Area (ft²)	717.51
LMTD	17.78
Total Heat Transferred (BTU/hr)	154,861
Surface Effectiveness (Eta)	0.8901
Sensible Heat Transferred (BTU/hr)	154,861
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	117.91	°F	
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	$Pv = (W*Rv*P)/(Ra+(W*Rv)) =$	0.451874518	psia	Equation [11]
Dry Air Pressure:	$Pa = P - Pv =$	13.86312548	psia	Equation [4]
Dry Air Density:	$Rho\ a = (144/53.352)*(Pa/(459.67+T)) =$	0.064782961	lbm/ft^3	Equation [5]
Water Vapor Density:	$Rho\ v = (144/85.778)*(Pv/(459.67+T)) =$	0.001313386	lbm/ft^3	Equation [6]
Moist Air Density:	$Rho = Rho\ a + Rho\ v =$	0.066096347	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.598498195	psia	Equation [8]
Moist Air Relative Humidity:	$RH = Pv / Ps =$	28.26869116	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Back Coil Inlet Conditions (Clean)

[See Attachment H]

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	32,483.00 acfm	82.00 gpm
Inlet Dry Bulb Temp	°F	105.00 °F
Inlet Wet Bulb Temp	°F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000

Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000

Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]

Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347

Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00

Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370

Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Thermal Margin Assessment (Clean)

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Fouling Was Input by User

Test Data

Data Date
Air Flow (acfm)
Air Dry Bulb Temp In (°F)
Air Dry Bulb Temp Out (°F)
Relative Humidity In (%)
Relative Humidity Out (%)
Wet Bulb Temp In (°F)
Wet Bulb Temp Out (°F)
Atmospheric Pressure
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)
Condensate Temperature (°F)

Extrapolation Data

Tube Flow (gpm)	82.00
Air Flow (acfm)	29,197.64
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	117.9
Inlet Relative Humidity (%)	28.27
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

Adjusted to match Front Coil mass flow

Input Fouling Factor	0.000000

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
Thermal Margin Assessment (Clean)

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,515.94	40,774.19
Inlet Temperature (°F)	117.91	100.00
Outlet Temperature (°F)	104.11	109.65
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	5,740.10
LMTD	
Total Heat Transferred (BTU/hr)	391,980
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	391,980
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,515.94	40,774.19
Inlet Temperature (°F)	117.91	107.13
Outlet Temperature (°F)	115.55	110.43
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	116.73	108.78
Skin Temperature (°F)	111.31	111.29
Velocity ***	5,911.62	1.51
Reynold's Number	1,673	9,835
Prandtl Number	0.7276	4.0991
Bulk Visc (lbm/ft·hr)	0.0473	1.5024
Skin Visc (lbm/ft·hr)		1.4650
Density (lbm/ft³)	0.0651	61.8772
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0156	0.3661

Tube-Side hi (BTU/hr·ft²·°F)	565.21
j Factor	0.0114
Air-Side ho (BTU/hr·ft²·°F)	20.00
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	12.00
Effective Area (ft²)	717.51
LMTD	7.79
Total Heat Transferred (BTU/hr)	67,057
Surface Effectiveness (Eta)	0.8806
Sensible Heat Transferred (BTU/hr)	67,057
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

Thermal Margin Assessment (Clean)

Extrapolation Calculation for Row 2(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	113,515.94	40,774.19
Inlet Temperature (°F)	115.55	105.95
Outlet Temperature (°F)	113.45	108.87
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	114.50	107.41
Skin Temperature (°F)	109.68	109.66
Velocity ***	5,911.62	1.51
Reynold's Number	1,678	9,699
Prandtl Number	0.7278	4.1624
Bulk Visc (lbm/ft·hr)	0.0471	1.5235
Skin Visc (lbm/ft·hr)		1.4891
Density (lbm/ft^3)	0.0653	61.8962
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3656

Tube-Side hi (BTU/hr·ft^2·°F)	560.51
j Factor	0.0114
Air-Side ho (BTU/hr·ft^2·°F)	19.98
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	
U Overall (BTU/hr·ft^2·°F)	11.96
Effective Area (ft^2)	717.51
LMTD	6.94
Total Heat Transferred (BTU/hr)	59,607
Surface Effectiveness (Eta)	0.8807
Sensible Heat Transferred (BTU/hr)	59,607
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	113,515.94	40,774.19
Inlet Temperature (°F)	113.45	104.37
Outlet Temperature (°F)	111.47	107.13
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	112.46	105.75
Skin Temperature (°F)	107.91	107.89
Velocity ***	5,911.62	1.51
Reynold's Number	1,683	9,535
Prandtl Number	0.7279	4.2411
Bulk Visc (lbm/ft·hr)	0.0470	1.5497
Skin Visc (lbm/ft·hr)		1.5160
Density (lbm/ft^3)	0.0655	61.9189
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0155	0.3650

Tube-Side hi (BTU/hr·ft^2·°F)	554.75
j Factor	0.0114
Air-Side ho (BTU/hr·ft^2·°F)	19.96
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	
U Overall (BTU/hr·ft^2·°F)	11.92
Effective Area (ft^2)	717.51
LMTD	6.57
Total Heat Transferred (BTU/hr)	56,181
Surface Effectiveness (Eta)	0.8808
Sensible Heat Transferred (BTU/hr)	56,181
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,515.94	40,774.19
Inlet Temperature (°F)	111.47	103.54
Outlet Temperature (°F)	109.75	105.95
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	110.61	104.74
Skin Temperature (°F)	106.64	106.62
Velocity ***	5,911.62	1.51
Reynold's Number	1,687	9,436
Prandtl Number	0.7280	4.2903
Bulk Visc (lbm/ft·hr)	0.0469	1.5660
Skin Visc (lbm/ft·hr)		1.5358
Density (lbm/ft^3)	0.0657	61.9325
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0155	0.3646

Tube-Side hi (BTU/hr·ft^2·°F)	550.95
j Factor	0.0114
Air-Side ho (BTU/hr·ft^2·°F)	19.94
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	
U Overall (BTU/hr·ft^2·°F)	11.88
Effective Area (ft^2)	717.51
LMTD	5.75
Total Heat Transferred (BTU/hr)	49,001
Surface Effectiveness (Eta)	0.8809
Sensible Heat Transferred (BTU/hr)	49,001
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,515.94	40,774.19
Inlet Temperature (°F)	109.75	102.04
Outlet Temperature (°F)	108.07	104.37
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	108.91	103.21
Skin Temperature (°F)	105.06	105.05
Velocity ***	5,911.62	1.51
Reynold's Number	1,691	9,286
Prandtl Number	0.7281	4.3668
Bulk Visc (lbm/ft·hr)	0.0468	1.5913
Skin Visc (lbm/ft·hr)		1.5610
Density (lbm/ft^3)	0.0659	61.9529
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0154	0.3640

Tube-Side hi (BTU/hr·ft^2·°F)	545.30
j Factor	0.0114
Air-Side ho (BTU/hr·ft^2·°F)	19.92
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	
U Overall (BTU/hr·ft^2·°F)	11.84
Effective Area (ft^2)	717.51
LMTD	5.59
Total Heat Transferred (BTU/hr)	47,456
Surface Effectiveness (Eta)	0.8810
Sensible Heat Transferred (BTU/hr)	47,456
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,515.94	40,774.19
Inlet Temperature (°F)	108.07	101.58
Outlet Temperature (°F)	106.67	103.54
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	107.37	102.56
Skin Temperature (°F)	104.13	104.11
Velocity ***	5,911.62	1.51
Reynold's Number	1,695	9,222
Prandtl Number	0.7282	4.3999
Bulk Visc (lbm/ft·hr)	0.0467	1.6023
Skin Visc (lbm/ft·hr)		1.5763
Density (lbm/ft³)	0.0661	61.9614
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0154	0.3638

Tube-Side hi (BTU/hr·ft²·°F)	542.64
j Factor	0.0113
Air-Side ho (BTU/hr·ft²·°F)	19.90
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	11.81
Effective Area (ft²)	717.51
LMTD	4.72
Total Heat Transferred (BTU/hr)	39,978
Surface Effectiveness (Eta)	0.8811
Sensible Heat Transferred (BTU/hr)	39,978
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,515.94	40,774.19
Inlet Temperature (°F)	106.67	100.05
Outlet Temperature (°F)	105.24	102.04
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	105.95	101.05
Skin Temperature (°F)	102.66	102.64
Velocity ***	5,911.62	1.51
Reynold's Number	1,698	9,076
Prandtl Number	0.7282	4.4784
Bulk Visc (lbm/ft·hr)	0.0466	1.6282
Skin Visc (lbm/ft·hr)		1.6008
Density (lbm/ft³)	0.0663	61.9810
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0154	0.3632

Tube-Side hi (BTU/hr·ft²·°F)	536.87
j Factor	0.0113
Air-Side ho (BTU/hr·ft²·°F)	19.89
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	11.77
Effective Area (ft²)	717.51
LMTD	4.81
Total Heat Transferred (BTU/hr)	40,596
Surface Effectiveness (Eta)	0.8812
Sensible Heat Transferred (BTU/hr)	40,596
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Thermal Margin Assessment (Clean)

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,515.94	40,774.19
Inlet Temperature (°F)	105.24	100.00
Outlet Temperature (°F)	104.11	101.58
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	104.67	100.79
Skin Temperature (°F)	102.07	102.05
Velocity ***	5,911.62	1.51
Reynold's Number	1,701	9,051
Prandtl Number	0.7283	4.4920
Bulk Visc (lbm/ft·hr)	0.0465	1.6327
Skin Visc (lbm/ft·hr)		1.6108
Density (lbm/ft³)	0.0664	61.9843
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0153	0.3631

Tube-Side hi (BTU/hr·ft²·°F)	535.60
j Factor	0.0113
Air-Side ho (BTU/hr·ft²·°F)	19.87
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	
U Overall (BTU/hr·ft²·°F)	11.75
Effective Area (ft²)	717.51
LMTD	3.81
Total Heat Transferred (BTU/hr)	32,105
Surface Effectiveness (Eta)	0.8812
Sensible Heat Transferred (BTU/hr)	32,105
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment G to
Proto-Power Calculation
97-198
Revision A

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	33,546.00 acfm	118.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle VY Cooler 04A
	j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	118.00
Air Flow (acfm)	30,610.10
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	113,114.65	58,675.06	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	121.40	112.83	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	2,870.05
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	752,589
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	752,589
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	113,114.65	58,675.06	Tube-Side hi (BTU/hr·ft^2·°F)	765.98
Inlet Temperature (°F)	148.00	106.18	j Factor	0.0105
Outlet Temperature (°F)	139.79	114.11	Air-Side ho (BTU/hr·ft^2·°F)	18.33
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	143.89	110.14		
Skin Temperature (°F)	123.85	116.48	U Overall (BTU/hr·ft^2·°F)	9.68
Velocity ***	5,890.72	2.17	Effective Area (ft^2)	717.51
Reynold's Number	2,146	14,350	LMTD	33.44
Prandtl Number	0.7255	4.0375	Total Heat Transferred (BTU/hr)	232,327
Bulk Visc (lbm/ft·hr)	0.0490	1.4819		
Skin Visc (lbm/ft·hr)		1.3923	Surface Effectiveness (Eta)	0.8891
Density (lbm/ft^3)	0.0624	61.8580	Sensible Heat Transferred (BTU/hr)	232,327
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0162	0.3666	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	113,114.65	58,675.06	Tube-Side hi (BTU/hr·ft²·°F)	757.33
Inlet Temperature (°F)	139.79	104.98	j Factor	0.0104
Outlet Temperature (°F)	132.98	111.56	Air-Side ho (BTU/hr·ft²·°F)	18.26
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	136.38	108.27		
Skin Temperature (°F)	119.70	113.59	U Overall (BTU/hr·ft²·°F)	9.64
Velocity ***	5,890.72	2.17	Effective Area (ft²)	717.51
Reynold's Number	2,166	14,081	LMTD	27.86
Prandtl Number	0.7262	4.1223	Total Heat Transferred (BTU/hr)	192,721
Bulk Visc (lbm/ft·hr)	0.0485	1.5102		
Skin Visc (lbm/ft·hr)		1.4321	Surface Effectiveness (Eta)	0.8895
Density (lbm/ft³)	0.0632	61.8843	Sensible Heat Transferred (BTU/hr)	192,721
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0161	0.3659	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	113,114.65	58,675.06	Tube-Side hi (BTU/hr·ft²·°F)	736.03
Inlet Temperature (°F)	132.98	99.98	j Factor	0.0104
Outlet Temperature (°F)	126.56	106.18	Air-Side ho (BTU/hr·ft²·°F)	18.20
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	129.77	103.08		
Skin Temperature (°F)	113.99	108.24	U Overall (BTU/hr·ft²·°F)	9.57
Velocity ***	5,890.72	2.17	Effective Area (ft²)	717.51
Reynold's Number	2,185	13,345	LMTD	26.45
Prandtl Number	0.7267	4.3732	Total Heat Transferred (BTU/hr)	181,650
Bulk Visc (lbm/ft·hr)	0.0481	1.5934		
Skin Visc (lbm/ft·hr)		1.5107	Surface Effectiveness (Eta)	0.8898
Density (lbm/ft³)	0.0638	61.9545	Sensible Heat Transferred (BTU/hr)	181,650
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0159	0.3640	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	113,114.65	58,675.06
Inlet Temperature (°F)	126.56	100.01
Outlet Temperature (°F)	121.40	104.98
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	123.98	102.49
Skin Temperature (°F)	111.28	106.66
Velocity ***	5,890.72	2.17
Reynold's Number	2,202	13,263
Prandtl Number	0.7271	4.4031
Bulk Visc (lbm/ft·hr)	0.0477	1.6033
Skin Visc (lbm/ft·hr)		1.5353
Density (lbm/ft^3)	0.0644	61.9622
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0158	0.3637

Tube-Side hi (BTU/hr·ft^2·°F)	732.58
j Factor	0.0104
Air-Side ho (BTU/hr·ft^2·°F)	18.14
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	9.55
Effective Area (ft^2)	717.51
LMTD	21.30
Total Heat Transferred (BTU/hr)	145,892
Surface Effectiveness (Eta)	0.8901
Sensible Heat Transferred (BTU/hr)	145,892
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	121.4	°F	
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.064393864	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001305497	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.065699362	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.76150085	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	25.65281294	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Back Coil Inlet Conditions (Service)

[See Attachment H]

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	32,483.00 acfm	82.00 gpm
Inlet Dry Bulb Temp	°F	105.00 °F
Inlet Wet Bulb Temp	°F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.001500
Air-Side Fouling	0.000000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
Thermal Margin Assessment (Service)

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used ←

Test Data

Data Date
Air Flow (acfm)
Air Dry Bulb Temp In (°F)
Air Dry Bulb Temp Out (°F)
Relative Humidity In (%)
Relative Humidity Out (%)
Wet Bulb Temp In (°F)
Wet Bulb Temp Out (°F)
Atmospheric Pressure
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)
Condensate Temperature (°F)

Extrapolation Data

Tube Flow (gpm)	82.00
Air Flow (acfm)	29,270.07 ←
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	121.4
Inlet Relative Humidity (%)	25.65
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

Adjusted to match front Coil mass flow

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	113,114.62	40,774.19	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	121.40	100.00	j Factor	
Outlet Temperature (°F)	106.11	110.66	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	5,740.10
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	432,781
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	432,781
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	113,114.62	40,774.19	Tube-Side hi (BTU/hr·ft^2·°F)	568.14
Inlet Temperature (°F)	121.40	107.96	j Factor	0.0114
Outlet Temperature (°F)	118.92	111.41	Air-Side ho (BTU/hr·ft^2·°F)	19.99
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	120.16	109.68		
Skin Temperature (°F)	114.52	112.28	U Overall (BTU/hr·ft^2·°F)	9.48
Velocity ***	5,890.72	1.51	Effective Area (ft^2)	717.51
Reynold's Number	1,660	9,926	LMTD	10.34
Prandtl Number	0.7274	4.0581	Total Heat Transferred (BTU/hr)	70,295
Bulk Visc (lbm/ft·hr)	0.0475	1.4887		
Skin Visc (lbm/ft·hr)		1.4506	Surface Effectiveness (Eta)	0.8807
Density (lbm/ft^3)	0.0647	61.8645	Sensible Heat Transferred (BTU/hr)	70,295
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0157	0.3664	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,114.62	40,774.19
Inlet Temperature (°F)	118.92	106.79
Outlet Temperature (°F)	116.68	109.90
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	117.80	108.35
Skin Temperature (°F)	112.72	110.70
Velocity ***	5,890.72	1.51
Reynold's Number	1,665	9,792
Prandtl Number	0.7276	4.1188
Bulk Visc (lbm/ft·hr)	0.0473	1.5090
Skin Visc (lbm/ft·hr)		1.4736
Density (lbm/ft^3)	0.0649	61.8832
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0156	0.3659

Tube-Side hi (BTU/hr·ft^2·°F)	563.70
j Factor	0.0114
Air-Side ho (BTU/hr·ft^2·°F)	19.97
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	9.46
Effective Area (ft^2)	717.51
LMTD	9.33
Total Heat Transferred (BTU/hr)	63,266
Surface Effectiveness (Eta)	0.8808
Sensible Heat Transferred (BTU/hr)	63,266
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,114.62	40,774.19
Inlet Temperature (°F)	116.68	104.96
Outlet Temperature (°F)	114.52	107.96
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	115.60	106.46
Skin Temperature (°F)	110.70	108.76
Velocity ***	5,890.72	1.51
Reynold's Number	1,670	9,605
Prandtl Number	0.7277	4.2072
Bulk Visc (lbm/ft·hr)	0.0472	1.5384
Skin Visc (lbm/ft·hr)		1.5027
Density (lbm/ft^3)	0.0652	61.9092
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3652

Tube-Side hi (BTU/hr·ft^2·°F)	557.33
j Factor	0.0114
Air-Side ho (BTU/hr·ft^2·°F)	19.94
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
U Overall (BTU/hr·ft^2·°F)	9.42
Effective Area (ft^2)	717.51
LMTD	9.02
Total Heat Transferred (BTU/hr)	61,001
Surface Effectiveness (Eta)	0.8809
Sensible Heat Transferred (BTU/hr)	61,001
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Thermal Margin Assessment (Service)

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	113,114.62	40,774.19	Tube-Side hi (BTU/hr·ft²·°F)	553.68
Inlet Temperature (°F)	114.52	104.15	j Factor	0.0114
Outlet Temperature (°F)	112.62	106.79	Air-Side ho (BTU/hr·ft²·°F)	19.92
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	113.57	105.47		
Skin Temperature (°F)	109.23	107.51	U Overall (BTU/hr·ft²·°F)	9.40
Velocity ***	5,890.72	1.51	Effective Area (ft²)	717.51
Reynold's Number	1,675	9,508	LMTD	8.00
Prandtl Number	0.7278	4.2547	Total Heat Transferred (BTU/hr)	53,942
Bulk Visc (lbm/ft·hr)	0.0471	1.5542		
Skin Visc (lbm/ft·hr)		1.5218	Surface Effectiveness (Eta)	0.8810
Density (lbm/ft³)	0.0654	61.9227	Sensible Heat Transferred (BTU/hr)	53,942
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0155	0.3649	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	113,114.62	40,774.19	Tube-Side hi (BTU/hr·ft²·°F)	547.12
Inlet Temperature (°F)	112.62	102.35	j Factor	0.0114
Outlet Temperature (°F)	110.74	104.96	Air-Side ho (BTU/hr·ft²·°F)	19.90
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.02228812
Average Temp (°F)	111.68	103.65		
Skin Temperature (°F)	107.39	105.70	U Overall (BTU/hr·ft²·°F)	9.37
Velocity ***	5,890.72	1.51	Effective Area (ft²)	717.51
Reynold's Number	1,679	9,330	LMTD	7.92
Prandtl Number	0.7279	4.3443	Total Heat Transferred (BTU/hr)	53,234
Bulk Visc (lbm/ft·hr)	0.0470	1.5839		
Skin Visc (lbm/ft·hr)		1.5505	Surface Effectiveness (Eta)	0.8811
Density (lbm/ft³)	0.0656	61.9469	Sensible Heat Transferred (BTU/hr)	53,234
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0155	0.3642	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	113,114.62	40,774.19	Tube-Side hi (BTU/hr·ft^2·°F)	544.55
Inlet Temperature (°F)	110.74	101.90	j Factor	0.0114
Outlet Temperature (°F)	109.12	104.15	Air-Side ho (BTU/hr·ft^2·°F)	19.88
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	109.93	103.02		
Skin Temperature (°F)	106.24	104.78	U Overall (BTU/hr·ft^2·°F)	9.35
Velocity ***	5,890.72	1.51	Effective Area (ft^2)	717.51
Reynold's Number	1,683	9,268	LMTD	6.82
Prandtl Number	0.7280	4.3762	Total Heat Transferred (BTU/hr)	45,755
Bulk Visc (lbm/ft·hr)	0.0468	1.5944		
Skin Visc (lbm/ft·hr)		1.5653	Surface Effectiveness (Eta)	0.8812
Density (lbm/ft^3)	0.0658	61.9553	Sensible Heat Transferred (BTU/hr)	45,755
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0155	0.3639	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	113,114.62	40,774.19	Tube-Side hi (BTU/hr·ft^2·°F)	537.64
Inlet Temperature (°F)	109.12	100.05	j Factor	0.0114
Outlet Temperature (°F)	107.46	102.35	Air-Side ho (BTU/hr·ft^2·°F)	19.87
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.02228812
Average Temp (°F)	108.29	101.20		
Skin Temperature (°F)	104.52	103.03	U Overall (BTU/hr·ft^2·°F)	9.32
Velocity ***	5,890.72	1.51	Effective Area (ft^2)	717.51
Reynold's Number	1,687	9,090	LMTD	7.00
Prandtl Number	0.7281	4.4704	Total Heat Transferred (BTU/hr)	46,832
Bulk Visc (lbm/ft·hr)	0.0467	1.6255		
Skin Visc (lbm/ft·hr)		1.5944	Surface Effectiveness (Eta)	0.8813
Density (lbm/ft^3)	0.0660	61.9790	Sensible Heat Transferred (BTU/hr)	46,832
Cp (BTU/lbm·°F)	0.2402	0.9990	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0154	0.3632	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	113,114.62	40,774.19
Inlet Temperature (°F)	107.46	100.01
Outlet Temperature (°F)	106.11	101.90
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	106.79	100.95
Skin Temperature (°F)	103.68	102.46
Velocity ***	5,890.72	1.51
Reynold's Number	1,690	9,067
Prandtl Number	0.7282	4.4832
Bulk Visc (lbm/ft·hr)	0.0466	1.6298
Skin Visc (lbm/ft·hr)		1.6039
Density (lbm/ft³)	0.0662	61.9822
Cp (BTU/lbm·°F)	0.2402	0.9990
K (BTU/hr·ft·°F)	0.0154	0.3632

Tube-Side hi (BTU/hr·ft²·°F)	536.44
j Factor	0.0114
Air-Side ho (BTU/hr·ft²·°F)	19.85
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.02228812
U Overall (BTU/hr·ft²·°F)	9.31
Effective Area (ft²)	717.51
LMTD	5.76
Total Heat Transferred (BTU/hr)	38,457
Surface Effectiveness (Eta)	0.8814
Sensible Heat Transferred (BTU/hr)	38,457
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment H to
Proto-Power Calculation
97-198
Revision A

Moist Air Properties

Equations for calculating moist air properties are compiled and/or derived in Proto-Power Calculation 96-069, Reference (1), relying on References (2) and (3) as the principal sources of information. This attachment summarizes the equations pertinent to the moist air conditions calculated for heat exchanger model development. The applicable material has been extracted from Reference (1) leaving equation numbering as it appears in Reference (1) for ease of cross reference.

1. NOMENCLATURE

m_a = Mass of Dry Air, lbm
m_v = Mass of Water Vapor, lbm
P = Atmospheric Pressure, lbf/in^2
P_a = Dry Air Pressure, lbf/in^2
P_s = Saturated Air Pressure, lbf/in^2
P_v = Water Vapor Pressure, lbf/in^2
R_a = Gas constant of Dry Air
R_v = Gas constant of Water Vapor
T = Dry Bulb Temperature, °F
T_w = Wet Bulb Temperature, °F
V = Moist air Volume, ft^3
W = Moist air Specific Humidity
x_v = Mole Fraction of Water Vapor in Moist Air
x_s = Mole Fraction of Water Vapor in Saturated Air
ϕ = Moist Air Relative Humidity
ρ = Moist air Density, lbm/ft^3
ρ_a = Dry Air Density, lbm/ft^3
ρ_v = Water Vapor Density, lbm/ft^3

2. REFERENCES

(1) Proto-Power Calculation 96-069, Fluid Properties - Moist Air - Range 8°F to 300°F, Revision -, dated 12/2/96

(2) Heating Ventilating, and Air Conditioning Analysis and Design, F. C. McQuiston and J. D. Parker, Second Edition, John Wiley & Sons, Inc., 1982

(3) ASHRAE Handbook 1981 Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1982

3. MOIST AIR DENSITY

For dry air:

$$P_a = P - P_v$$ Equation [4]

$$\rho_a = \left(\frac{144}{R_a}\right)\frac{P_a}{(459.67+T)}$$ Equation [5]

where:

R_a = 53.352 (ft-lbf)/(lbm-°R)

For water vapor:

$$\rho_v = \left(\frac{144}{R_v}\right)\frac{P_v}{(459.67+T)}$$ Equation [6]

where:
R_v = 85.778 (ft-lbf)/(lbm-°R)

For moist air:

$$\rho = \rho_a + \rho_v$$ Equation [7]

4. SATURATED WATER VAPOR PRESSURE

$$P_s(T) = a + bT + cT^2 + dT^3 + eT^4 + fT^5$$ Equation [8]

Where;
a = 0.02358607
b = 0.001007276
c = 0.00001888033
d = 0.0000003775047
e = 4.871208E-10
f = 2.109071E-11

5. WATER VAPOR PRESSURE

$$f(T_w) = a + bT_w + cT_w^2 + dT_w^3 + eT_w^4 + fT_w^5$$ Equation [9]

$$P_v(P,T,T_w) = \frac{\left[(2T_w - T - 2800)f(T_w)\right] - P(T_w - T)}{(T_w - 2800)}$$ Equation [10]

Where:
a = 0.02358607
b = 0.001007276
c = 0.00001888033
d = 0.0000003775047
e = 4.871208E-10
f = 2.109071E-11

$$P_v = \frac{WR_v\, P}{R_a + (WR_v)}$$ Equation [11]

6. MOIST AIR SPECIFIC HUMIDITY

$$W = \frac{m_v}{m_a} = \frac{\rho_v}{\rho_a}$$ Equation [12]

Where:

$$m_v = \frac{P_v V}{R_v(459.67 + T)}$$ Equation [13]

$$m_a = \frac{P_a V}{R_a(459.67 + T)}$$ Equation [14]

7. MOIST AIR RELATIVE HUMIDITY

$$\phi = \frac{x_v}{x_s} = \frac{P_v}{P_s}$$ Equation [15]

Moist Air Properties -- Given Dry Bulb and Relative Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	70	°F	
Moist Air Relative Humidity:	RH =	40	%	
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^{2})+(d*T^{3})+(e*T^{4})+(f*T^{5}) =$	0.363236046	psia	Equation [8]
Vapor Pressure:	Pv = RH*Ps	0.145294418	psia	Equation [15]
Dry Air Pressure:	Pa =P - Pv =	14.16970558	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.072204994	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.000460501	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.072665495	lbm/ft^3	Equation [7]
Specific Humidity:	W = Rho v / Rho a =	0.006377682		Equation [12]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Coil Specification Conditions

Moist Air Properties -- Given Dry Bulb and Wet Bulb Temperatures *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	150	°F	
Wet Bulb Temperature:	Tw =	92.00	°F	
Wet Bulb Temp. Function:	$F(Tw) = a+(b*Tw)+(c*Tw^2)+(d*Tw^3)+(e*Tw^4)+(f*Tw^5) =$	0.743918919		Equation [9]
Water Vapor Pressure:	$Pv = (((2*Tw-T-2800)*F(Tw))-P*(Tw-T))/(Tw-2800) =$	0.453253224	psia	Equation [10]
Dry Air Pressure:	Pa =P - Pv =	13.86174678	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.061367004	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001248052	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.062615056	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	3.721743953	psia	Equation [8]
Moist Air Specific Humidity:	W = Rho v / Rho a =	0.020337508		Equation [12]
Moist Air Relative Humidity:	RH = Pv /Ps =	12.17852	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Coil Benchmark Conditions

Moist Air Properties -- Given Dry Bulb and Wet Bulb Temperatures *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	148	°F	
Wet Bulb Temperature:	Tw =	91.60	°F	
Wet Bulb Temp. Function:	$F(Tw) = a+(b*Tw)+(c*Tw^{2})+(d*Tw^{3})+(e*Tw^{4})+(f*Tw^{5}) =$	0.734713202		Equation [9]
Water Vapor Pressure:	Pv = (((2*Tw-T-2800)*F(Tw))-P*(Tw-T))/(Tw-2800) =	0.451915914	psia	Equation [10]
Dry Air Pressure:	Pa =P - Pv =	13.86308409	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.061574919	lbm/ft^{3}	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001248465	lbm/ft^{3}	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.062823384	lbm/ft^{3}	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^{2})+(d*T^{3})+(e*T^{4})+(f*T^{5}) =$	3.541336347	psia	Equation [8]
Moist Air Specific Humidity:	W = Rho v / Rho a =	0.020275546		Equation [12]
Moist Air Relative Humidity:	RH = Pv /Ps =	12.76117	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* LaSalle Station Reference Conditions

Moist Air Properties -- Given Dry Bulb and Relative Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	148	°F	
Moist Air Relative Humidity:	RH =	12.76	%	
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	3.541336347	psia	Equation [8]
Vapor Pressure:	Pv = RH*Ps	0.451874518	psia	Equation [15]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.061575103	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001248351	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.062823454	lbm/ft^3	Equation [7]
Specific Humidity:	W = Rho v / Rho a =	0.020273629		Equation [12]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* LaSalle Station Reference Conditions (RH = 12.76%)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	104.11	°F	
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	$Pv = (W*Rv*P)/(Ra+(W*Rv)) =$	0.451874518	psia	Equation [11]
Dry Air Pressure:	$Pa = P - Pv =$	13.86312548	psia	Equation [4]
Dry Air Density:	$Rho\ a = (144/53.352)*(Pa/(459.67+T)) =$	0.066368695	lbm/ft^3	Equation [5]
Water Vapor Density:	$Rho\ v = (144/85.778)*(Pv/(459.67+T)) =$	0.001345534	lbm/ft^3	Equation [6]
Moist Air Density:	$Rho = Rho\ a + Rho\ v =$	0.067714229	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.074274081	psia	Equation [8]
Moist Air Relative Humidity:	$RH = Pv / Ps =$	42.06324307	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Back Coil Outlet Conditions (Clean)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	106.11	°F	
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	$Pv = (W*Rv*P)/(Ra+(W*Rv)) =$	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	$Rho\ a = (144/53.352)*(Pa/(459.67+T)) =$	0.066134085	lbm/ft^3	Equation [5]
Water Vapor Density:	$Rho\ v = (144/85.778)*(Pv/(459.67+T)) =$	0.001340778	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.067474863	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.139525693	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	39.65461425	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Back Coil Outlet Conditions (Service)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	118.45	°F	
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.06472245	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001312159	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.066034609	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.622837933	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	27.8447101	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Back Coil Outlet Conditions (Limiting Flow)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	116.7	°F	
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.064918963	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001316143	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.066235106	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.545095034	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	29.2457427	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Back Coil Outlet Conditions (Tube f = 0.0000)

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	120.05	°F	
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.064543819	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001308537	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.065852356	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	1.696833221	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	26.63046152	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Back Coil Outlet Conditions (Tube f = 0.0040)

Attachment I to
Proto-Power Calculation
97-198
Revision A

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Data Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

Limiting Flow Analysis -- 66.5 gpm

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	33,546.00 acfm	118.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.002000 ←
Air-Side Fouling	0.002000 ←
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle VY Cooler 04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

Limiting Flow Analysis -- 66.5 gpm

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	39.20
Air Flow (acfm)	29,956.75
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110,700.30	19,492.05	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	130.41	124.99	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.03171750
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	2,870.05
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	487,103
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	487,103
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110,700.30	19,492.05	Tube-Side hi (BTU/hr·ft^2·°F)	274.08
Inlet Temperature (°F)	148.00	113.92	j Factor	0.0105
Outlet Temperature (°F)	143.62	126.39	Air-Side ho (BTU/hr·ft^2·°F)	18.09
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.03171750
Average Temp (°F)	145.81	120.15		
Skin Temperature (°F)	135.07	129.53	U Overall (BTU/hr·ft^2·°F)	6.75
Velocity ***	5,764.99	0.72	Effective Area (ft^2)	717.51
Reynold's Number	2,095	5,254	LMTD	25.09
Prandtl Number	0.7253	3.6287	Total Heat Transferred (BTU/hr)	121,421
Bulk Visc (lbm/ft·hr)	0.0491	1.3445		
Skin Visc (lbm/ft·hr)		1.2339	Surface Effectiveness (Eta)	0.8904
Density (lbm/ft^3)	0.0620	61.7093	Sensible Heat Transferred (BTU/hr)	121,421
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3701	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110,700.30	19,492.05	Tube-Side hi (BTU/hr·ft²·°F)	267.85
Inlet Temperature (°F)	143.62	112.16	j Factor	0.0105
Outlet Temperature (°F)	139.60	123.60	Air-Side ho (BTU/hr·ft²·°F)	18.05
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03171750
Average Temp (°F)	141.61	117.88		
Skin Temperature (°F)	131.74	126.68	U Overall (BTU/hr·ft²·°F)	6.68
Velocity ***	5,764.99	0.72	Effective Area (ft²)	717.51
Reynold's Number	2,106	5,142	LMTD	23.21
Prandtl Number	0.7257	3.7155	Total Heat Transferred (BTU/hr)	111,304
Bulk Visc (lbm/ft·hr)	0.0488	1.3738		
Skin Visc (lbm/ft·hr)		1.2660	Surface Effectiveness (Eta)	0.8906
Density (lbm/ft³)	0.0625	61.7443	Sensible Heat Transferred (BTU/hr)	111,304
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0162	0.3693	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110,700.30	19,492.05	Tube-Side hi (BTU/hr·ft²·°F)	239.61
Inlet Temperature (°F)	139.60	99.96	j Factor	0.0105
Outlet Temperature (°F)	134.69	113.92	Air-Side ho (BTU/hr·ft²·°F)	18.01
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03171750
Average Temp (°F)	137.14	106.94		
Skin Temperature (°F)	125.10	118.92	U Overall (BTU/hr·ft²·°F)	6.40
Velocity ***	5,764.99	0.72	Effective Area (ft²)	717.51
Reynold's Number	2,118	4,614	LMTD	29.60
Prandtl Number	0.7261	4.1846	Total Heat Transferred (BTU/hr)	135,899
Bulk Visc (lbm/ft·hr)	0.0486	1.5309		
Skin Visc (lbm/ft·hr)		1.3603	Surface Effectiveness (Eta)	0.8908
Density (lbm/ft³)	0.0630	61.9027	Sensible Heat Transferred (BTU/hr)	135,899
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0161	0.3654	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

Limiting Flow Analysis -- 66.5 gpm

Extrapolation Calculation for Row 4(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	110,700.30	19,492.05
Inlet Temperature (°F)	134.69	99.99
Outlet Temperature (°F)	130.41	112.16
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	132.55	106.08
Skin Temperature (°F)	122.03	116.64
Velocity ***	5,764.99	0.72
Reynold's Number	2,131	4,574
Prandtl Number	0.7265	4.2255
Bulk Visc (lbm/ft·hr)	0.0483	1.5445
Skin Visc (lbm/ft·hr)		1.3902
Density (lbm/ft^3)	0.0634	61.9144
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0160	0.3651

Tube-Side hi (BTU/hr·ft^2·°F)	236.84
j Factor	0.0105
Air-Side ho (BTU/hr·ft^2·°F)	17.97
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.03171750
U Overall (BTU/hr·ft^2·°F)	6.36
Effective Area (ft^2)	717.51
LMTD	25.95
Total Heat Transferred (BTU/hr)	118,479
Surface Effectiveness (Eta)	0.8910
Sensible Heat Transferred (BTU/hr)	118,479
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Moist Air Properties -- Given Dry Bulb and Specific Humidity *

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	130.41	°F	
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.063410627	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001285563	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.06469619	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	2.249688203	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	20.08609537	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

* Back Coil Inlet Conditions (Limiting Flow Analysis - 66.5 gpm)

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	32,483.00 acfm	82.00 gpm
Inlet Dry Bulb Temp	°F	105.00 °F
Inlet Wet Bulb Temp	°F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.002000
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	27.30	
Air Flow (acfm)	29,089.80	← Adjusted to match front Coil mass flow
Tube Inlet Temp (°F)	100.00	
Air Inlet Temp (°F)	130.4	
Inlet Relative Humidity (%)	20.09	
Inlet Wet Bulb Temp (°F)	0.00	
Atmospheric Pressure	14.315	

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

Limiting Flow Analysis -- 66.5 gpm

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,700.34	13,574.82
Inlet Temperature (°F)	130.41	100.00
Outlet Temperature (°F)	118.45	124.42
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.03171750
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	5,740.10
LMTD	
Total Heat Transferred (BTU/hr)	331,168
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	331,168
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,700.34	13,574.82
Inlet Temperature (°F)	130.41	121.01
Outlet Temperature (°F)	129.43	125.01
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	129.92	123.01
Skin Temperature (°F)	127.69	126.44
Velocity ***	5,764.99	0.50
Reynold's Number	1,603	3,758
Prandtl Number	0.7267	3.5243
Bulk Visc (lbm/ft·hr)	0.0481	1.3091
Skin Visc (lbm/ft·hr)		1.2686
Density (lbm/ft³)	0.0635	61.6644
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3710

Tube-Side hi (BTU/hr·ft²·°F)	168.64
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.81
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.03171750
U Overall (BTU/hr·ft²·°F)	5.64
Effective Area (ft²)	717.51
LMTD	6.70
Total Heat Transferred (BTU/hr)	27,115
Surface Effectiveness (Eta)	0.8816
Sensible Heat Transferred (BTU/hr)	27,115
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,700.34	13,574.82
Inlet Temperature (°F)	129.43	119.71
Outlet Temperature (°F)	128.42	123.83
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	128.93	121.77
Skin Temperature (°F)	126.63	125.35
Velocity ***	5,764.99	0.50
Reynold's Number	1,605	3,715
Prandtl Number	0.7268	3.5691
Bulk Visc (lbm/ft·hr)	0.0480	1.3243
Skin Visc (lbm/ft·hr)		1.2813
Density (lbm/ft³)	0.0636	61.6841
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3706

Tube-Side hi (BTU/hr·ft²·°F)	166.24
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.80
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.03171750
U Overall (BTU/hr·ft²·°F)	5.60
Effective Area (ft²)	717.51
LMTD	6.95
Total Heat Transferred (BTU/hr)	27,904
Surface Effectiveness (Eta)	0.8816
Sensible Heat Transferred (BTU/hr)	27,904
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,700.34	13,574.82
Inlet Temperature (°F)	128.42	115.70
Outlet Temperature (°F)	127.12	121.01
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	127.77	118.36
Skin Temperature (°F)	124.81	123.16
Velocity ***	5,764.99	0.50
Reynold's Number	1,608	3,597
Prandtl Number	0.7269	3.6970
Bulk Visc (lbm/ft·hr)	0.0480	1.3676
Skin Visc (lbm/ft·hr)		1.3073
Density (lbm/ft³)	0.0638	61.7370
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3695

Tube-Side hi (BTU/hr·ft²·°F)	159.78
j Factor	0.0115
Air-Side ho (BTU/hr·ft²·°F)	19.79
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.03171750
U Overall (BTU/hr·ft²·°F)	5.49
Effective Area (ft²)	717.51
LMTD	9.15
Total Heat Transferred (BTU/hr)	36,016
Surface Effectiveness (Eta)	0.8817
Sensible Heat Transferred (BTU/hr)	36,016
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

Limiting Flow Analysis -- 66.5 gpm

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,700.34	13,574.82
Inlet Temperature (°F)	127.12	114.45
Outlet Temperature (°F)	125.83	119.71
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	126.48	117.08
Skin Temperature (°F)	123.55	121.91
Velocity ***	5,764.99	0.50
Reynold's Number	1,611	3,554
Prandtl Number	0.7269	3.7468
Bulk Visc (lbm/ft·hr)	0.0479	1.3844
Skin Visc (lbm/ft·hr)		1.3226
Density (lbm/ft³)	0.0639	61.7564
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3690

Tube-Side hi (BTU/hr·ft²·°F)	157.26
j Factor	0.0115
Air-Side ho (BTU/hr·ft²·°F)	19.77
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.03171750
U Overall (BTU/hr·ft²·°F)	5.44
Effective Area (ft²)	717.51
LMTD	9.14
Total Heat Transferred (BTU/hr)	35,666
Surface Effectiveness (Eta)	0.8817
Sensible Heat Transferred (BTU/hr)	35,666
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,700.34	13,574.82
Inlet Temperature (°F)	125.83	108.77
Outlet Temperature (°F)	124.14	115.70
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	124.99	112.24
Skin Temperature (°F)	121.13	118.98
Velocity ***	5,764.99	0.50
Reynold's Number	1,614	3,390
Prandtl Number	0.7271	3.9460
Bulk Visc (lbm/ft·hr)	0.0478	1.4513
Skin Visc (lbm/ft·hr)		1.3595
Density (lbm/ft³)	0.0641	61.8280
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3673

Tube-Side hi (BTU/hr·ft²·°F)	148.04
j Factor	0.0115
Air-Side ho (BTU/hr·ft²·°F)	19.76
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.03171750
U Overall (BTU/hr·ft²·°F)	5.27
Effective Area (ft²)	717.51
LMTD	12.41
Total Heat Transferred (BTU/hr)	46,951
Surface Effectiveness (Eta)	0.8818
Sensible Heat Transferred (BTU/hr)	46,951
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110,700.34	13,574.82	Tube-Side hi (BTU/hr·ft²·°F)	145.86
Inlet Temperature (°F)	124.14	107.89	j Factor	0.0115
Outlet Temperature (°F)	122.53	114.45	Air-Side ho (BTU/hr·ft²·°F)	19.74
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03171750
Average Temp (°F)	123.34	111.17		
Skin Temperature (°F)	119.68	117.65	U Overall (BTU/hr·ft²·°F)	5.23
Velocity ***	5,764.99	0.50	Effective Area (ft²)	717.51
Reynold's Number	1,617	3,354	LMTD	11.85
Prandtl Number	0.7272	3.9922	Total Heat Transferred (BTU/hr)	44,460
Bulk Visc (lbm/ft·hr)	0.0477	1.4667		
Skin Visc (lbm/ft·hr)		1.3768	Surface Effectiveness (Eta)	0.8819
Density (lbm/ft³)	0.0643	61.8433	Sensible Heat Transferred (BTU/hr)	44,460
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0158	0.3670	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110,700.34	13,574.82	Tube-Side hi (BTU/hr·ft²·°F)	132.83
Inlet Temperature (°F)	122.53	100.01	j Factor	0.0115
Outlet Temperature (°F)	120.39	108.77	Air-Side ho (BTU/hr·ft²·°F)	19.72
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.03171750
Average Temp (°F)	121.46	104.39		
Skin Temperature (°F)	116.59	113.88	U Overall (BTU/hr·ft²·°F)	4.97
Velocity ***	5,764.99	0.50	Effective Area (ft²)	717.51
Reynold's Number	1,621	3,130	LMTD	16.67
Prandtl Number	0.7273	4.3075	Total Heat Transferred (BTU/hr)	59,406
Bulk Visc (lbm/ft·hr)	0.0476	1.5717		
Skin Visc (lbm/ft·hr)		1.4280	Surface Effectiveness (Eta)	0.8820
Density (lbm/ft³)	0.0645	61.9371	Sensible Heat Transferred (BTU/hr)	59,406
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0157	0.3645	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	110,700.34	13,574.82
Inlet Temperature (°F)	120.39	99.98
Outlet Temperature (°F)	118.45	107.89
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	119.42	103.94
Skin Temperature (°F)	115.02	112.57
Velocity ***	5,764.99	0.50
Reynold's Number	1,626	3,115
Prandtl Number	0.7274	4.3302
Bulk Visc (lbm/ft·hr)	0.0474	1.5792
Skin Visc (lbm/ft·hr)		1.4465
Density (lbm/ft³)	0.0647	61.9432
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3643

Tube-Side hi (BTU/hr·ft²·°F)	131.75
j Factor	0.0115
Air-Side ho (BTU/hr·ft²·°F)	19.70
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.03171750
U Overall (BTU/hr·ft²·°F)	4.94
Effective Area (ft²)	717.51
LMTD	15.13
Total Heat Transferred (BTU/hr)	53,651
Surface Effectiveness (Eta)	0.8821
Sensible Heat Transferred (BTU/hr)	53,651
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment J to
Proto-Power Calculation
97-198
Revision A

Proto-HX Analytical Uncertainty Calculation
[Circular Fin Air Coil Application]

Purpose

The purpose of the following calculation is to evaluate the analytical uncertainty associated with the analysis of test data and the computation of heat transfer rate at a given extrapolation condition. This calculation focuses only on the parameters that are not measured during the thermal performance test but factor into the analysis of the test results. Test parameter measurement uncertainty is treated separately in the test uncertainty analysis. The calculation of analytical uncertainty is derived for a typical Air Cooler with "n" tube rows.

Governing Heat Transfer Equations

Heat transfer calculations associated with a heat exchanger generally reduce to satisfying the following equations:

1) $q = U\,A_o\,LMTD$

Where:

q = Heat transfer rate at test conditions (BTU/hr)
U = Overall heat transfer coefficient at test conditions (BTU/hr-°F-ft^2)
A_o = Heat transfer surface area referenced to outside (air-side) surface (ft^2)
LMTD = Log Mean Temperature Difference at test conditions (°F)

and

2) $q = \dot{m} c_p (T_{c_o} - T_{c_i}) = \rho Q c_p \Delta T$

Where:

q = Heat transfer rate at test conditions (BTU/hr)
$\dot{m}$ = Mass flow rate at test conditions (lbm/hr)
c_p = Specific heat of cooling water at test conditions (Btu/lb_m-°F)
T_{ci} = Tube-side inlet temperature at test conditions (°F)
T_{co} = Tube-side outlet temperature at test conditions (°F)
ρ = Density of tube-side fluid at average bulk temperature at test conditions (lb_m/ft^3)
Q = Volumetric flow rate of tube-side fluid at test conditions (gpm)

The first equation is used, in Proto-HX, to evaluate the heat transfer rate from test data. The analytical uncertainties associated with evaluating the fluid properties are usually the only contributors to the overall uncertainty when using this equation. For a given test condition, the right hand side of the second equation is evaluated such that it matches the measured heat transfer rate, "q". In Proto-HX, this means iterating on fouling factor, and therefore "U", until the heat transfer equation is satisfied.

The following equations are used for this iteration:

$$3)\qquad R = \frac{1}{U} = \frac{A_o \, LMTD_{Test}}{q_{Test}}$$

Where:

R = Overall heat transfer thermal resistance at test conditions (hr-°F-ft^2/ BTU)
U = Overall heat transfer coefficient at test conditions (BTU/hr-°F-ft^2)
A_o = Outside heat transfer surface area (ft^2)
LMTD = Log Mean Temperature Difference at test conditions (°F)
q = Heat transfer rate at test conditions (BTU/hr)

and

$$4)\qquad R_f = R - \frac{1}{h_o \eta_s} - R_w - \left(\frac{A_o}{A_i}\right)\frac{1}{h_i}$$

Where:

R_f = Fouling resistance (hr-°F-ft^2/ BTU)
R = Overall heat transfer thermal resistance at test conditions (hr-°F-ft^2/ BTU)
h_o = Outside convection film coefficient at test conditions (BTU/hr-°F-ft^2)
η_s = Fin surface effectiveness
R_w = Wall thermal resistance at test conditions (hr-°F-ft^2/ BTU)
A_o = Outside heat transfer surface area (ft^2)
A_i = Inside heat transfer surface area (ft^2)
h_i = Inside convection film coefficient at test conditions (BTU/hr-°F-ft^2)

These same equations must be satisfied when evaluating the capacity of a heat exchanger at a given fouling condition (i.e., when extrapolating to the limiting thermal condition). The following equations are used for the extrapolation process:

$$5)\qquad R^* = R_f + \frac{1}{h_o * \eta_s} + R_w* + \left(\frac{A_o}{A_i}\right)\frac{1}{h_i *}$$

Where:

R^* = Overall thermal resistance at extrapolation conditions (hr-°F-ft^2/ BTU)
R_f = Calculated fouling resistance (hr-°F-ft^2/ BTU)
h_{o*} = Outside convection film coefficient at extrapolation conditions (BTU/hr-°F-ft^2)
η_s = Fin surface effectiveness
R_w* = Wall thermal resistance at extrapolation conditions(hr-°F-ft^2/ BTU)
A_o = Outside heat transfer surface area (ft^2)
A_i = Inside heat transfer surface area (ft^2)

h_i* = Inside convection film coefficient at extrapolation conditions (BTU/hr-°F-ft^2)

and

6) $q^* = (1/R^*)\ A_o\ LMTD^* = U^* A_o\ LMTD^*$

where:

q* = Heat transfer rate at extrapolation conditions (BTU/hr)
R* = Overall thermal resistance at extrapolation conditions (hr-°F-ft^2/ BTU)
U* = Overall heat coefficient at extrapolation conditions (BTU/hr-°F-ft^2)
Ao = Heat transfer surface area referenced to outside surface (ft^2)
LMTD* = Log Mean Temperature Difference at extrapolation conditions (°F)

Analytical Uncertainty Calculation Methodology

The method for calculating the analytical uncertainty associated with this performance analysis method is illustrated as follows:

Given a function D = f(A,B,C)

The effect on D of slight changes in the independent variables A, B, and C may be calculated by taking the partial derivatives of D with respect to each of the independent variables. Accordingly, the change in the value of D (i.e., ΔD) due to changes in each of the independent variables (ΔA, ΔB, ΔC) may be represented by the following equation:

$$\Delta \mathrm{D} = \frac{\partial D}{\partial A}\Delta A + \frac{\partial D}{\partial B}\Delta B + \frac{\partial D}{\partial C}\Delta C$$

If ΔA, ΔB, ΔC are the known (or estimated) errors of the independent variables, then the error, ΔD, associated with the derived value, D, is calculated. The most probable one standard deviation error representative of ΔD would be the statistical root mean squared value derived as follows:

$$\Delta \mathrm{D} = \left[\left(\frac{\partial \mathrm{D}}{\partial \mathrm{A}}\Delta \mathrm{A}\right)^2 + \left(\frac{\partial \mathrm{D}}{\partial \mathrm{B}}\Delta \mathrm{B}\right)^2 + \left(\frac{\partial \mathrm{D}}{\partial \mathrm{C}}\Delta \mathrm{C}\right)^2\right]^{1/2} = U_D$$

Expressing the uncertainty in terms of a percentage of the value of D is simply a matter of including division by the value of D as follows:

$$\frac{U_D}{\mathrm{D}} = \left[\left(\frac{\partial \mathrm{D}}{\partial \mathrm{A}}\right)^2\left(\frac{\Delta \mathrm{A}}{\mathrm{D}}\right)^2 + \left(\frac{\partial \mathrm{D}}{\partial \mathrm{B}}\right)^2\left(\frac{\Delta \mathrm{B}}{\mathrm{D}}\right)^2 + \left(\frac{\partial \mathrm{D}}{\partial \mathrm{C}}\right)^2\left(\frac{\Delta \mathrm{C}}{\mathrm{D}}\right)^2\right]^{1/2}$$

The next six sections of this document provide a step by step approach to calculating the analytical uncertainty associated with the six thermal performance equations outlined above. The specific terms to be evaluated from these equations are as follows:

1) Heat transfer area, A_o and area uncertainty, U_{A_o}
2) Test condition heat transfer rate, q and heat transfer uncertainty, U_q
3) Test condition thermal resistance, R and thermal resistance uncertainty, U_R
4) Observed overall fouling resistance, R_f fouling resistance uncertainty, U_{R_f}
5) Extrapolation condition thermal resistance, R* and thermal resistance uncertainty, U_{R^*}
6) Extrapolation condition heat transfer rate, q* and heat transfer rate uncertainty, U_{q^*}

All uncertainty equations used in this calculation are based on the methods of Reference [1]. It is assumed that all independent variables in each equation have no influence on each other. For example, in Equation (6), LMTD* and the overall heat transfer coefficient, U*, are independent of each other. More specific assumptions are stated in each section as applicable.

For the rating analysis case (i.e., fouling factor is specified and not calculated from test data), equations 2, 3 and 4 above are not applicable because the uncertainty in the specified fouling factor is zero. The analytical uncertainty calculation, therefore, is reduced to an accounting of area uncertainty from equation 1 and the uncertainty in extrapolation terms per equations 5 and 6.

1) Uncertainty in Calculation of Heat Transfer Area (A_o)

Governing Equation

$q = U\, A_o\, LMTD$

For Air Coolers with circular fins, the outside tube surface area, the fin surface area and the total outside surface area are given by the following expressions:

$$A_{o_{Tube}} = \pi\, N_T N_L L_C d_o (1 - \lambda\, t_{FR})$$

$$A_{o_{Fin}} = \pi \lambda N_T N_L L_C \left[H_F t_{FT} + (H_F + d_o)\sqrt{\left(\frac{H_F - d_o}{2}\right)^2 + \left(\frac{t_{FR} - t_{FT}}{2}\right)^2} \right]$$

$$A_{o_{Total}} = \pi N_T N_L L_C \left\{ d_o(1 - \lambda t_{FR}) + \lambda \left[H_F t_{FT} + (H_F + d_o)\sqrt{\left(\frac{H_F - d_o}{2}\right)^2 + \left(\frac{t_{FR} - t_{FT}}{2}\right)^2} \right] \right\}$$

where:

N_T = Number of tubes per row
N_L = Number of active tube rows
L_C = Effective tube (coil) length (in)
d_o = Tube outside diameter (in)
λ = Fin pitch (fins/inch)
H_F = Fin height (in)
t_{FR} = Thickness of fin at root (in)
t_{FT} = Thickness of fin at tip (in)

For the case where $t_{FR} = t_{FT} = t_F$, the total area equation reduces to the following:

$$A_{o_{Total}} = \pi N_T N_L L_C \left\{ d_o(1 - \lambda t_F) + \lambda \left[H_F t_F + (H_F + d_o)\frac{(H_F - d_o)}{2} \right] \right\}$$

$$A_{o_{Total}} = \pi N_T N_L L_C \left\{ d_o - \lambda d_o t_F + \frac{\lambda}{2}\left[2 H_F t_F + H_F^2 - d_o^2\right] \right\}$$

Assumptions

$U_{N_T} = 0$

$U_{N_L} = 0$

$U_{\lambda} = 0$

Analysis

$$\frac{U_{Ao}}{A_o} = \left\{ \left(\frac{\partial A_o}{\partial d_o}\right)^2 \left(\frac{U_{d_o}}{A_o}\right)^2 + \left(\frac{\partial A_o}{\partial L_c}\right)^2 \left(\frac{U_{L_c}}{A_o}\right)^2 + \left(\frac{\partial A_o}{\partial t_F}\right)^2 \left(\frac{U_{t_F}}{A_o}\right)^2 + \left(\frac{\partial A_o}{\partial H_F}\right)^2 \left(\frac{U_{H_F}}{A_o}\right)^2 \right\}^{1/2}$$

where,

$$\left(\frac{\partial A_o}{\partial d_o}\right) = \pi N_T N_L L_c \{(1 - \lambda t_F) - \lambda d_o\}$$

$$\left(\frac{\partial A_o}{\partial L_c}\right) = \pi N_T N_L \left\{ d_o - \lambda d_o t_F + \frac{\lambda}{2}\left[2H_F t_F + H_F^2 - d_o^2\right] \right\}$$

$$\left(\frac{\partial A_o}{\partial t_F}\right) = \pi N_T N_L L_c \lambda \{H_F - d_o\}$$

$$\left(\frac{\partial A_o}{\partial H_F}\right) = \pi N_T N_L L_c \lambda \{t_F + H_F\}$$

2) Uncertainty in Calculation of Heat Transfer Rate at Test Conditions

Governing Equation

$$q_{Test} = \dot{m} c_p (T_{c_o} - T_{c_i}) = \rho Q c_p \Delta T$$

Assumptions

$$U_{\Delta T} = 0$$

$$U_{Q_{SW}} = 0$$

(i.e., temperature and flow rate in the governing equation are measured values with no analytical uncertainites)

Analysis

$$\frac{U_{q_{test}}}{q_{test}} = \left[\left(\frac{\partial q_{test}}{\partial \rho}\right)^2 \left(\frac{U_\rho}{q_{test}}\right)^2 + \left(\frac{\partial q_{test}}{\partial Q_{SW}}\right)^2 \left(\frac{U_Q}{q_{test}}\right)^2 + \left(\frac{\partial q_{test}}{\partial c_p}\right)^2 \left(\frac{U_{c_p}}{q_{test}}\right)^2 + \left(\frac{\partial q_{test}}{\partial \Delta T}\right)^2 \left(\frac{U_{\Delta T}}{q_{test}}\right)^2 \right]^{1/2}$$

$$\frac{U_{q_{test}}}{q_{test}} = \left[(Q_{SW}\, c_p\, \Delta T)^2 \left(\frac{U_\rho}{q_{test}}\right)^2 + (\rho Q_{SW}\, \Delta T)^2 \left(\frac{U_{c_p}}{q_{test}}\right)^2 \right]^{1/2}$$

3) Uncertainty in Calculation of Thermal Resistance at Test Conditions

Governing Equation

$$R = \frac{1}{U} = \frac{A_o\ LMTD_{Test}}{q_{Test}}$$

Assumptions

U_{LMTD} is negligible

Analysis

$$\frac{U_R}{R} = \left[\left(\frac{\partial R}{\partial A_o}\right)^2\left(\frac{U_{A_o}}{R}\right)^2 + \left(\frac{\partial R}{\partial LMTD}\right)^2\left(\frac{U_{LMTD}}{R}\right)^2 + \left(\frac{\partial R}{\partial q_{test}}\right)^2\left(\frac{U_{q_{test}}}{R}\right)^2\right]^{1/2}$$

$$\frac{U_R}{R} = \left[\left(\frac{LMTD}{q_{test}}\right)^2\left(\frac{U_{A_o}}{R}\right)^2 + \left(\frac{-A_o LMTD}{q_{test}^{\ 2}}\right)^2\left(\frac{U_{q_{test}}}{R}\right)^2\right]^{1/2}$$

U_{A_o} (Evaluated in Section 1)

$U_{q_{test}}$ (Evaluated in Section 2)

4) Uncertainty in Calculation of Fouling Factor at Test Conditions

Governing Equation

$$R_f = R - \frac{1}{h_o \eta_s} - R_w - \left(\frac{A_o}{A_i}\right)\frac{1}{h_i} = R - \frac{1}{h_{o,eff}} - R_w - \left(\frac{A_o}{A_i}\right)\frac{1}{h_i}$$

Where,

$h_{o,eff}$ = effective outside film coefficient = (h_o) x (η_s)

Assumptions

$$\left(\frac{\partial R_f}{\partial A_o}\right)^2\left(\frac{U_{A_o}}{R_f}\right)^2 \approx 0$$

$$\left(\frac{\partial R_f}{\partial A_i}\right)^2\left(\frac{U_{A_i}}{R_f}\right)^2 \approx 0$$

(i.e., the uncertainty in dimensions is negligible compared to the thermal resistance and convection coefficient uncertainties)

Analysis

$$\frac{U_{R_f}}{R_f} = \left[\left(\frac{\partial R_f}{\partial R}\right)^2\left(\frac{U_R}{R_f}\right)^2 + \left(\frac{\partial R_f}{\partial h_{o,eff}}\right)^2\left(\frac{U_{h_{o,eff}}}{R_f}\right)^2 + \left(\frac{\partial R_f}{\partial R_w}\right)^2\left(\frac{U_{R_w}}{R_f}\right)^2 + \left(\frac{\partial R_f}{\partial h_i}\right)^2\left(\frac{U_{h_i}}{R_f}\right)^2\right]^{1/2}$$

$$\frac{U_{R_f}}{R_f} = \left[\left(\frac{U_R}{R_f}\right)^2 + \left(\frac{1}{h_{o,eff}^{\,2}}\right)^2\left(\frac{U_{h_{o,eff}}}{R_f}\right)^2 + \left(\frac{U_{R_w}}{R_f}\right)^2 + \left(\frac{A_o}{A_i}\frac{1}{h_i^{\,2}}\right)^2\left(\frac{U_{h_i}}{R_f}\right)^2\right]^{1/2}$$

U_R (Evaluated in Section 3)

5) Uncertainty in Calculation of Heat Transfer Resistance at Extrapolation Conditions

Governing Equation

$$R^* = R_f + \frac{1}{h_{o,eff}{}^*} + R_w + \left(\frac{A_o}{A_i}\right)\frac{1}{h_i{}^*}$$

Assumptions

$$\left(\frac{\partial R^*}{\partial A_o}\right)^2\left(\frac{U_{A_o}}{R^*}\right)^2 \approx 0$$

$$\left(\frac{\partial R^*}{\partial A_i}\right)^2\left(\frac{U_{A_i}}{R^*}\right)^2 \approx 0$$

(i.e., the uncertainty in dimensions is negligible compared to the thermal resistance and convection coefficient uncertainties)

Analysis

$$\frac{U_{R^*}}{R^*} = \left[\left(\frac{\partial R^*}{\partial R_f}\right)^2\left(\frac{U_{R_f}}{R^*}\right)^2 + \left(\frac{\partial R^*}{\partial h_{o,eff}{}^*}\right)^2\left(\frac{U_{h_{o,eff}{}^*}}{R^*}\right)^2 + \left(\frac{\partial R^*}{\partial R_w}\right)^2\left(\frac{U_{R_w}}{R^*}\right)^2 + \left(\frac{\partial R^*}{\partial h_i{}^*}\right)^2\left(\frac{U_{h_i{}^*}}{R^*}\right)^2\right]^{1/2}$$

$$\frac{U_{R^*}}{R^*} = \left[\left(\frac{U_{R_f}}{R^*}\right)^2 + \left(-\frac{1}{h_{o,eff}{}^{*2}}\right)^2\left(\frac{U_{h_{o,eff}{}^*}}{R^*}\right)^2 + \left(\frac{U_{R_w}}{R^*}\right)^2 + \left(-\frac{A_o}{A_i}\frac{1}{h_i{}^{*2}}\right)^2\left(\frac{U_{h_i{}^*}}{R^*}\right)^2\right]^{1/2}$$

U_{R_f} (Evaluated in Section 4)

U_{R_f} = 0 (for extrapolation calculations only, i.e., no fouling calculation)

6) Uncertainty in Calculation of Heat Transfer Rate at Extrapolation Conditions

Governing Equation

$q^* = (1/R^*)\ (A_o)\ (LMTD^*)$

Assumptions

$U_{\mathrm{LMTD}} \approx 0.0$

Analysis

$$\frac{U_{q^*}}{q^*} = \left[\left(\frac{\partial q^*}{\partial R^*}\right)^2 \left(\frac{U_{R^*}}{q^*}\right)^2 + \left(\frac{\partial q^*}{\partial A_o}\right)^2 \left(\frac{U_{Q^*}}{q^*}\right)^2 + \left(\frac{\partial q^*}{\partial (\mathrm{LMTD}^*)}\right)^2 \left(\frac{U_{\mathrm{LMTD}^*}}{q^*}\right)^2 \right]^{1/2}$$

$$\frac{U_q^*}{q^*} = \left[\left(-R^{*-2} A_o\ \mathrm{LMTD}^*\right)^2 \left(\frac{U_{R^*}}{q^*}\right)^2 + \left(\frac{1}{R^*} \mathrm{LMTD}^*\right)^2 \left(\frac{U_{A_o}}{q^*}\right)^2 \right]^{1/2}$$

U_R (Evaluated in Section 5)

U_{A_o} (Evaluated in Section 1)

7) Uncertainty in Calculation of Extrapolated Heat Transfer for Entire Unit

The uncertainties in extrapolated heat transfer, computed for each tube row, are combined in the following manner to yield an overall uncertainty value for the entire air cooler.

$q_{tot} = q_1 + q_2 + q_3 \ldots\ldots + q_n$

where, " n " is the number of tube rows in the unit.

$$\frac{Uq_{tot}}{q_{tot}} = \left[\left(\frac{\partial q_{tot}}{\partial q_1}\right)^2 \left(\frac{Uq_1}{q_{tot}}\right)^2 + \left(\frac{\partial q_{tot}}{\partial q_2}\right)^2 \left(\frac{Uq_2}{q_{tot}}\right)^2 + \left(\frac{\partial q_{tot}}{\partial q_2}\right)^2 \left(\frac{Uq_3}{q_{tot}}\right)^2 + \ldots\ldots\ldots\ldots \left(\frac{\partial q_{tot}}{\partial q_n}\right)^2 \left(\frac{Uq_n}{q_{tot}}\right)^2\right]^{1/2}$$

Assuming that the extrapolated heat transfer rates of the various rows do not depend on each other, the above expression becomes:

$$\frac{Uq_{tot}}{q_{tot}} = \left[\left(\frac{Uq_1}{q_{tot}}\right)^2 + \left(\frac{Uq_2}{q_{tot}}\right)^2 + \left(\frac{Uq_3}{q_{tot}}\right)^2 + \ldots\ldots\ldots\ldots \left(\frac{Uq_n}{q_{tot}}\right)^2\right]^{1/2}$$

FRONT COIL

Definition of Analytical Uncertainty Analysis Terms

Ao/Ai =	Heat transfer area ratio
di (in) =	Tube inside diameter
Ao (ft^2) =	Outside heat transfer area
do (in) =	Tube outside diameter
Udo/do (%) =	Uncertainty in tube outside diameter (as a percentage)
Udo =	Uncertainty in tube outside diameter (absolute)
Nt =	Number of tubes in given row
Nl =	Number of rows in heat exchanger
Lambda (fins/in) =	Fin pitch
L (Ft) =	Tube length
UL/L (%) =	Uncertainty in tube length (as a percentage)
UL(ft) =	Uncertainty in tube length (absolute)
tfin (in) =	Fin thickness
Utfin/tfin (%) =	Uncertainty in fin thickness (as a percentage)
Utfin (in) =	Uncertainty in fin thickness (absolute)
hfin (in) =	Fin height
Uhfin/hfin (%) =	Uncertainty in fin height (as a percentage)
Uhfin (in) =	Uncertainty in fin height (absolute)
Mdotc (lbm/hr) =	Cooling water mass flow rate
Q (Ft^3/hr) =	Cooling water volumetric flow rate
DT (DegF) =	Cooling water temperature difference (inlet to outlet)
rho (lbm/ft^3) =	Cooling water density
Urho/rho (%) =	Uncertainty in cooling water density (as a percentage)
Urho =	Uncertainty in cooling water density (absolute)
Cp (Btu/lbm/DegF) =	Cooling water specific heat
UCp/Cp (%) =	Uncertainty in cooling water specific heat (as a percentage)
UCp =	Uncertainty in cooling water specific heat (absolute)
qtest (Btu/hr) =	Calculated test heat transfer for coil section
LMTD (DegF) =	Calculated log mean temperature difference
Uo =	Heat transfer coefficient
R = (1/Uo) =	Heat transfer resistance
Rf [(hr-DegF-ft^2)/Btu] =	Fouling resistance
Etas =	
ho [Btu/(hr-DegF-ft^2)] =	Outside film coefficient
ho(eff) [Btu/(hr-DegF-ft^2)] =	Effective outside film coefficient
Uho/ho (%) =	Uncertainty in outside film coefficient (as a percentage)
Uho =	Uncertainty in outside film coefficient (absolute)
hi [Btu/(hr-DegF-ft^2)] =	Inside film coefficient
Uhi/hi (%) =	Uncertainty in inside film coefficient (as a percentage)
Uhi =	Uncertainty in inside film coefficient (absolute)
Rw [(hr-DegF-ft^2)/Btu] =	Wall thermal resistance
URw/Rw (%) =	Uncertainty in wall resistance (as a percentage)
URw =	Uncertainty in wall resistance (absolute)

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Analytical Uncertainty Analysis -- Uncertainty Inputs

Parameter	Definition	Value (%)	
Udo/do	Uncertainty in tube outside diameter	8.00	(1)
ULc/Lc	Uncertainty in coil (tube) length	0.24	(2)
Utfin/tfin	Uncertainty in fin thickness	4.17	(3)
Uhfin/hfin	Uncertainty in circular fin height	1.48	(4)
Urho/rho	Uncertainty in cooling water density	2.00	(5)
UCp/Cp	Uncertainty in cooling water specific heat	2.00	(5)
Uho/ho	Uncertainty in outside film coefficient	15.00	(6)
Uhi/hi	Uncertainty in inside film coefficient	15.00	(7)
URw/Rw	Uncertainty in wall resistance	2.00	(5)

Notes:

(1)	Measurement of 5/8" +/- 0.05" yields an uncertainty of 8.0%
(2)	Measurement of 105" +/- 0.25" yields an uncertainty of 0.24%
(3)	Specified as 0.012" with estimated tolerance of 0.0005" yields an uncertainty of 4.17%
(4)	Measurement of 1.347" +/- 0.02" yields an uncertainty of 1.48%
(5)	Uncertainty in property values is estimated as 2%
(6)	Uncertainty in outside film coefficient is estimated as 15%
(7)	Uncertainty in inside film coefficient is estimated as 15%

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PROTO-HX 3.01 by Proto-Power Corporation (SN#PHX-0000) 07/10/98
ComEd -- LaSalle
Data Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	33546 acfm	118 gpm
Inlet Dry Bulb Temp	150 °F	105 °F
Inlet Wet Bulb Temp	92 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	
Tube Fluid Name		Fresh Water
Tube Fouling Factor		0.002
Air-Side Fouling		0.002
Design Heat Transfer (BTU/hr)		
Atmospheric Pressure		14.315
Sensible Heat Ratio		1
Performance Factor (% Reduction)		0
Heat Exchanger Type		Counter Flow
Fin Type		Circular Fins
Fin Configuration		LaSalle VY Cooler 04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)		105
Fin Pitch (Fins/Inch)		10
Fin Conductivity (BTU/hr·ft·°F)		128
Fin Tip Thickness (inches)		0.012
Fin Root Thickness (inches)		0.012
Circular Fin Height (inches)		1.347
Number of Coils Per Unit		2
Number of Tube Rows		4
Number of Tubes Per Row		20
Active Tubes Per Row		20
Tube Inside Diameter (in)		0.527
Tube Outside Diameter (in)		0.625
Longitudinal Tube Pitch (in)		2
Transverse Tube Pitch (in)		1.37
Number of Serpentines		2
Tube Wall Conductivity (BTU/hr·ft·°F)		225

PROTO-HX Report -- Fouling Calculation Output

Fouling Calculation Summary

There is no fouling calculation for the rating analysis case.

Uncertainty in use of design fouling in rating analysis is zero.

Blacked-out areas in the sheets that follow are related to the fouling factor calculation and are not applicable

PROTO-HX Report -- Extrapolation Calculation Output for Limiting Flow Case

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	19492.05	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	148	100	j Factor	
Outlet Temperature (°F)	130.4103	124.9938	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	2870.05
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	487103.2
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	487103.2
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	19492.05	Tube-Side hi (BTU/hr·ft²·°F)	274.0782
Inlet Temperature (°F)	148	113.9172	j Factor	0.010545
Outlet Temperature (°F)	143.6154	126.3906	Air-Side ho (BTU/hr·ft²·°F)	18.09153
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)	145.8077	120.1535		
Skin Temperature (°F)	135.0657	129.5346	U Overall (BTU/hr·ft²·°F)	6.74503
Velocity ***	5764.99	0.724046	Effective Area (ft²)	717.5125
Reynold's Number	2094.879	5253.983	LMTD	25.08881
Prandtl Number	0.725319	3.628692	Total Heat Transferred (BTU/hr)	121420.9
Bulk Visc (lbm/ft·hr)	0.049099	1.344496		
Skin Visc (lbm/ft·hr)		1.233925	Surface Effectiveness (Eta)	0.89039
Density (lbm/ft³)	0.062037	61.70928	Sensible Heat Transferred (BTU/hr)	121420.9
Cp (BTU/lbm·°F)	0.240245	0.998902	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.016263	0.370081	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	19492.05	Tube-Side hi (BTU/hr·ft²·°F)	267.8463
Inlet Temperature (°F)	143.6154	112.1624	j Factor	0.010526
Outlet Temperature (°F)	139.5961	123.5969	Air-Side ho (BTU/hr·ft²·°F)	18.05222
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)	141.6058	117.8787		
Skin Temperature (°F)	131.7434	126.6751	U Overall (BTU/hr·ft²·°F)	6.682724
Velocity ***	5764.99	0.723636	Effective Area (ft²)	717.5125
Reynold's Number	2106	5141.879	LMTD	23.21284
Prandtl Number	0.725703	3.71548	Total Heat Transferred (BTU/hr)	111304.1
Bulk Visc (lbm/ft·hr)	0.048839	1.373809		
Skin Visc (lbm/ft·hr)		1.265977	Surface Effectiveness (Eta)	0.890595
Density (lbm/ft³)	0.062453	61.74425	Sensible Heat Transferred (BTU/hr)	111304.1
Cp (BTU/lbm·°F)	0.240245	0.998801	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.016168	0.369311	Heat to Condensate (BTU/hr)	

PROTO-HX Report -- Extrapolation Calculation Output for Limiting Flow Case

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	19492.05	Tube-Side hi (BTU/hr·ft²·°F)	239.6102
Inlet Temperature (°F)	139.5961	99.9568	j Factor	0.010505
Outlet Temperature (°F)	134.6887	113.9172	Air-Side ho (BTU/hr·ft²·°F)	18.01047
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)	137.1425	106.9361		
Skin Temperature (°F)	125.0976	118.9204	U Overall (BTU/hr·ft²·°F)	6.397715
Velocity ***	5764.99	0.721783	Effective Area (ft²)	717.5125
Reynold's Number	2118.008	4614.305	LMTD	29.6048
Prandtl Number	0.726093	4.184624	Total Heat Transferred (BTU/hr)	135899.1
Bulk Visc (lbm/ft·hr)	0.048562	1.530883		
Skin Visc (lbm/ft·hr)		1.360255	Surface Effectiveness (Eta)	0.890812
Density (lbm/ft³)	0.062969	61.90271	Sensible Heat Transferred (BTU/hr)	135899.1
Cp (BTU/lbm·°F)	0.240245	0.998808	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.016068	0.365418	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	19492.05	Tube-Side hi (BTU/hr·ft²·°F)	236.841
Inlet Temperature (°F)	134.6887	99.99173	j Factor	0.010484
Outlet Temperature (°F)	130.4103	112.1624	Air-Side ho (BTU/hr·ft²·°F)	17.96752
Inlet Specific Humidity	0.020268		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity	0.020268		Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)	132.5496	106.0765		
Skin Temperature (°F)	122.0284	116.6443	U Overall (BTU/hr·ft²·°F)	6.362774
Velocity ***	5764.99	0.721646	Effective Area (ft²)	717.5125
Reynold's Number	2130.582	4573.701	LMTD	25.95168
Prandtl Number	0.726475	4.225521	Total Heat Transferred (BTU/hr)	118479
Bulk Visc (lbm/ft·hr)	0.048276	1.544474		
Skin Visc (lbm/ft·hr)		1.390163	Surface Effectiveness (Eta)	0.891036
Density (lbm/ft³)	0.063425	61.91445	Sensible Heat Transferred (BTU/hr)	118479
Cp (BTU/lbm·°F)	0.240245	0.998871	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015965	0.365098	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 1)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 24.14444854
Ao (ft^2) = 717.5125349
Ao/Ai = 29.71749526
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 20
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 8.75
UL/L (%) = 0.24
UL(ft) = 0.021

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.11225
Uhfin/hfin (%) = 1.48
Uhfin (ft) = 0.0016613

Mdotc* (lbm/hr) = 19492.05275
Q* (Ft^3/hr) = 315.8690532
DT* (DegF) = 12.47340151
rho* (lbm/ft^3) = 61.70928286
Urho*/rho* (%) = 2
Urho* = 1.234185657

Cp* (Btu/lbm/DegF) = 0.998902258
UCp*/Cp* (%) = 2
UCp* = 0.019978045

q* (Btu/hr) = 121420.9121
LMTD* (DegF) = 25.08881468
Uo* = 6.745029518
R* = (1/Uo*) = 0.14825732
Rf [(hr-DegF-ft^2)/Btu] = 0.031717495
Etas = 0.89038996
ho* [Btu/(hr-DegF-ft^2)] = 18.09152624
ho*(eff) [Btu/(hr-DegF-ft^2)] = 16.10851332
Uho*/ho* (%) = 15
Uho* = 2.416276998

hi* [Btu/(hr-DegF-ft^2)] = 274.078203
Uhi*/hi* (%) = 15
Uhi* = 41.11173045

Rw* [(hr-DegF-ft^2)/Btu] = 0.000247317
URw*/Rw* (%) = 2
URw* = 4.94634E-06

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Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 1)

1 **Analytical Uncertainty in Heat Transfer Surface Area**

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
717.51253	0.05208	0.00417	8.75000	0.02100	0.00100	0.00004	0.11225	0.00166	0.04877	34.99475
Derivatives:	-5904.62		82.00		7938.80		14942.99			

2 **Analytical Uncertainty in Test Heat Transfer Rate**

[redacted]

3 **Analytical Uncertainty in Observed Heat Transfer Resistance (R):**

[redacted]

4 **Analytical Uncertainty in Observed Rf**

[redacted]

5 **Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:**

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.14826	16.10851	2.41628	274.07820	41.11173	0.00025	0.00000	0.03172	0.00000[redacted]	0.12641	0.01874

6 **Analytical Uncertainty in Extrapolated Heat Transfer**

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
121420.9121	0.14826	0.01874	717.51253	34.99475	25.08881	0.13549	16451.57176

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 2)

I. PROTO-HX Output -- Fouling Calculation

[redacted]

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 24 14444854
Ao (ft^2) = 717.5125349
Ao/Ai = 29.71749526
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 20
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 8.75
UL/L (%) = 0.24
UL(ft) = 0.021

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0 0000417

hfin (ft) = 0.11225
Uhfin/hfin (%) = 1.48
Uhfin (ft) = 0.0016613

Mdotc* (lbm/hr) = 19492.05275
Q* (Ft^3/hr) = 315.6901592
DT* (DegF) = 11.43454036
rho* (lbm/ft^3) = 61.74425203
Urho*/rho* (%) = 2
Urho* = 1.234885041

Cp* (Btu/lbm/DegF) = 0.998800963
UCp*/Cp* (%) = 2
UCp* = 0.019976019

q* (Btu/hr) = 111304.1394
LMTD* (DegF) = 23.21284132
Uo* = 6.682723938
R* = (1/Uo*) = 0.149639579
Rf [(hr-DegF-ft^2)/Btu] = 0.031717495
Etas = 0.89059462
ho* [Btu/(hr-DegF-ft^2)] = 18.05221673
ho*(eff) [Btu/(hr-DegF-ft^2)] = 16.0772071
Uho*/ho* (%) = 15
Uho* = 2.411581068

hi* [Btu/(hr-DegF-ft^2)] = 267.8462713
Uhi*/hi* (%) = 15
Uhi* = 40.17694069

Rw* [(hr-DegF-ft^2)/Btu] = 0.000247317
URw*/Rw* (%) = 2
URw* = 4 94634E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 2).

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
717.51253	0.05208	0.00417	8.75000	0.02100	0.00100	0.00004	0.11225	0.00166	0.04877	34.99475
Derivatives:	-5904.62		82.00		7938.80		14942.99			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.14964	16.07721	2.41158	267.84627	40.17694	0.00025	0.00000	0.03172	**0.00000**	0.12750	0.01908

6 Analytical Uncertainty in Extrapolated Heat Transfer

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
111304.1394	0.14964	0.01908	717.51253	34.99475	23.21284	0.13651	15194.32143

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 3)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 24.14444854
Ao (ft^2) = 717.5125349
Ao/Ai = 29.71749526
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 20
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 8.75
UL/L (%) = 0.24
UL(ft) = 0.021

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.11225
Uhfin/hfin (%) = 1.48
Uhfin (ft) = 0.0016613

Mdotc* (lbm/hr) = 19492.05275
Q* (Ft^3/hr) = 314.8820572
DT* (DegF) = 13.96042496
rho* (lbm/ft^3) = 61.90271025
Urho*/rho* (%) = 2
Urho* = 1.238054205

Cp* (Btu/lbm/DegF) = 0.998807588
UCp*/Cp* (%) = 2
UCp* = 0.019976152

q* (Btu/hr) = 135699.0894
LMTD* (DegF) = 29.60480026
Uo* = 6.397715431
R* = (1/Uo*) = 0.156305796
Rf [(hr-DegF-ft^2)/Btu] = 0.031717495
Etas = 0.890812118
ho* [Btu/(hr-DegF-ft^2)] = 18.01046705
ho*(eff) [Btu/(hr-DegF-ft^2)] = 16.0439431
Uho*/ho* (%) = 15
Uho* = 2.406501466

hi* [Btu/(hr-DegF-ft^2)] = 239.6102017
Uhi*/hi* (%) = 15
Uhi* = 35.94153026

Rw* [(hr-DegF-ft^2)/Btu] = 0.000247317
URw*/Rw* (%) = 2
URw* = 4.94634E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 3)

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
717.51253	0.05208	0.00417	8.75000	0.02100	0.00100	0.00004	0.11225	0.00166	0.04877	34.99475
Derivatives:	-5904.62		82.00		7938.80		14942.99			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.15631	16.04394	2.40659	239.61020	35.94153	0.00025	0.00000	0.03172	**0.00000**	0.13321	0.02082

6 Analytical Uncertainty in Extrapolated Heat Transfer

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
135899.0894	0.15631	0.02082	717.51253	34.99475	29.60480	0.14185	19277.78082

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 4)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 24.14444854
Ao (ft^2) = 717.5125349
Ao/Ai = 29.71749526
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 20
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 8.75
UL/L (%) = 0.24
UL(ft) = 0.021

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.11225
Uhfin/hfin (%) = 1.48
Uhfin (ft) = 0.0016613

Mdotc* (lbm/hr) = 19492.05275
Q* (Ft^3/hr) = 314.8223573
DT* (DegF) = 12.17064276
rho* (lbm/ft^3) = 61.91444889
Urho*/rho* (%) = 2
Urho* = 1.238288978

Cp* (Btu/lbm/DegF) = 0.99887089
UCp*/Cp* (%) = 2
UCp* = 0.019977418

q* (Btu/hr) = 118479.0177
LMTD* (DegF) = 25.95167743
Uo* = 6.362774293
R* = (1/Uo*) = 0.157164148
Rf [(hr-DegF-ft^2)/Btu] = 0.031717495
Etas = 0.891036029
ho* [Btu/(hr-DegF-ft^2)] = 17.96751638
ho*(eff) [Btu/(hr-DegF-ft^2)] = 16.00970446
Uho*/ho* (%) = 15
Uho* = 2.401455668

hi* [Btu/(hr-DegF-ft^2)] = 236.8410238
Uhi*/hi* (%) = 15
Uhi* = 35.52615357

Rw* [(hr-DegF-ft^2)/Btu] = 0.000247317
URw*/Rw* (%) = 2
URw* = 4.94634E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 4)

1 **Analytical Uncertainty in Heat Transfer Surface Area**

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
717.51253	0.05208	0.00417	8.75000	0.02100	0.00100	0.00004	0.11225	0.00166	0.04877	34.99475
Derivatives:	-5904.62		82.00		7938.80		14942.99			

2 **Analytical Uncertainty in Test Heat Transfer Rate**

[redacted]

3 **Analytical Uncertainty in Observed Heat Transfer Resistance (R):**

[redacted]

4 **Analytical Uncertainty in Observed Rf**

[redacted]

5 **Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:**

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.15716	16.00970	2.40146	236.84102	35.52615	0.00025	0.00000	0.03172	**0.00000**	0.13377	0.02102

6 **Analytical Uncertainty in Extrapolated Heat Transfer**

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
118479.0177	0.15716	0 02102	717.51253	34.99475	25.95168	0.14239	16869.80234

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate

	Extrapolated Heat Transfer (Btu/hr)	Calculated Uncertainty (Btu/hr)	(Uq/q)^2
Row1	121420.9121	16451.5718	0.001141
Row2	111304.1394	15194.3214	0.000973
Row3	135899.0894	19277.7808	0.001566
Row4	118479.0177	16869.8023	0.001199
	487103.1586	**34025.6474**	**0.069853**
	qtot	**SRSS**	**SRSS**

Uqtot/qtot = **6.99%**

66.5 gpm Case

Proto-Power Calc: 97-198
Attachment: J
Rev: A Page 28 of 55

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate

	Extrapolated Heat Transfer (Btu/hr)	Calculated Uncertainty (Btu/hr)	(Uq/q)^2
Row1	243763.8082	28029.4595	0.001159
Row2	207526.0668	23896.4774	0.000842
Row3	203960.0295	23572.9269	0.000820
Row4	168102.0354	19442.7635	0.000558
	823351.9400	**47858.0836**	**0.058126**
	qtot	**SRSS**	**SRSS**

Uqtot/qtot = **5.81%**

(200 gpm Case)

Proto-Power Calc: 97-198
Attachment: J
Rev: A Page 29 of 55

BACK COIL

Definition of Analytical Uncertainty Analysis Terms

Ao/Ai =	Heat transfer area ratio
di (in) =	Tube inside diameter
Ao (ft^2) =	Outside heat transfer area
do (in) =	Tube outside diameter
Udo/do (%) =	Uncertainty in tube outside diameter (as a percentage)
Udo =	Uncertainty in tube outside diameter (absolute)
Nt =	Number of tubes in given row
Nl =	Number of rows in heat exchanger
Lambda (fins/in) =	Fin pitch
L (Ft) =	Tube length
UL/L (%) =	Uncertainty in tube length (as a percentage)
UL(ft) =	Uncertainty in tube length (absolute)
tfin (in) =	Fin thickness
Utfin/tfin (%) =	Uncertainty in fin thickness (as a percentage)
Utfin (in) =	Uncertainty in fin thickness (absolute)
hfin (in) =	Fin height
Uhfin/hfin (%) =	Uncertainty in fin height (as a percentage)
Uhfin (in) =	Uncertainty in fin height (absolute)
Mdotc (lbm/hr) =	Cooling water mass flow rate
Q (Ft^3/hr) =	Cooling water volumetric flow rate
DT (DegF) =	Cooling water temperature difference (inlet to outlet)
rho (lbm/ft^3) =	Cooling water density
Urho/rho (%) =	Uncertainty in cooling water density (as a percentage)
Urho =	Uncertainty in cooling water density (absolute)
Cp (Btu/lbm/DegF) =	Cooling water specific heat
UCp/Cp (%) =	Uncertainty in cooling water specific heat (as a percentage)
UCp =	Uncertainty in cooling water specific heat (absolute)
qtest (Btu/hr) =	Calculated test heat transfer for coil section
LMTD (DegF) =	Calculated log mean temperature difference
Uo =	Heat transfer coefficient
R = (1/Uo) =	Heat transfer resistance
Rf [(hr-DegF-ft^2)/Btu] =	Fouling resistance
Etas =	
ho [Btu/(hr-DegF-ft^2)] =	Outside film coefficient
ho(eff) [Btu/(hr-DegF-ft^2)] =	Effective outside film coefficient
Uho/ho (%) =	Uncertainty in outside film coefficient (as a percentage)
Uho =	Uncertainty in outside film coefficient (absolute)
hi [Btu/(hr-DegF-ft^2)] =	Inside film coefficient
Uhi/hi (%) =	Uncertainty in inside film coefficient (as a percentage)
Uhi =	Uncertainty in inside film coefficient (absolute)
Rw [(hr-DegF-ft^2)/Btu] =	Wall thermal resistance
URw/Rw (%) =	Uncertainty in wall resistance (as a percentage)
URw =	Uncertainty in wall resistance (absolute)

Analytical Uncertainty Analysis -- Uncertainty Inputs

Parameter	Definition	Value (%)	
Udo/do	Uncertainty in tube outside diameter	8.00	(1)
ULc/Lc	Uncertainty in coil (tube) length	0.24	(2)
Utfin/tfin	Uncertainty in fin thickness	4.17	(3)
Uhfin/hfin	Uncertainty in circular fin height	1.48	(4)
Urho/rho	Uncertainty in cooling water density	2.00	(5)
UCp/Cp	Uncertainty in cooling water specific heat	2.00	(5)
Uho/ho	Uncertainty in outside film coefficient	15.00	(6)
Uhi/hi	Uncertainty in inside film coefficient	15.00	(7)
URw/Rw	Uncertainty in wall resistance	2.00	(5)

Notes:

(1) Measurement of 5/8" +/- 0.05" yields an uncertainty of 8.0%
(2) Measurement of 105" +/- 0.25" yields an uncertainty of 0.24%
(3) Specified as 0.012" with estimated tolerance of 0.0005" yields an uncertainty of 4.17%
(4) Measurement of 1.347" +/- 0.02" yields an uncertainty of 1.48%
(5) Uncertainty in property values is estimated as 2%
(6) Uncertainty in outside film coefficient is estimated as 15%
(7) Uncertainty in inside film coefficient is estimated as 15%

16:07:41

PROTO-HX 3.01 by Proto-Power Corporation (SN#PHX-0000) 07/10/98
ComEd -- LaSalle
Data Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	32483 acfm	82 gpm
Inlet Dry Bulb Temp	°F	105 °F
Inlet Wet Bulb Temp	°F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	
Tube Fluid Name		Fresh Water
Tube Fouling Factor		0.002
Air-Side Fouling		0.002
Design Heat Transfer (BTU/hr)		
Atmospheric Pressure		14.315
Sensible Heat Ratio		1
Performance Factor (% Reduction)		0
Heat Exchanger Type		Counter Flow
Fin Type		Circular Fins
Fin Configuration		LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)		105
Fin Pitch (Fins/Inch)		10
Fin Conductivity (BTU/hr·ft·°F)		128
Fin Tip Thickness (inches)		0.012
Fin Root Thickness (inches)		0.012
Circular Fin Height (inches)		1.347
Number of Coils Per Unit		2
Number of Tube Rows		8
Number of Tubes Per Row		20
Active Tubes Per Row		20
Tube Inside Diameter (in)		0.527
Tube Outside Diameter (in)		0.625
Longitudinal Tube Pitch (in)		1.5
Transverse Tube Pitch (in)		1.37
Number of Serpentines		2
Tube Wall Conductivity (BTU/hr·ft·°F)		225

PROTO-HX Report -- Fouling Calculation Output

Fouling Calculation Summary

There is no fouling calculation for the rating analysis case.

Uncertainty in use of design fouling in rating analysis is zero.

Blacked-out areas in the sheets that follow are related to the fouling factor calculation and are not applicable

PROTO-HX Report -- Extrapolation Calculation Output for Limiting Flow Case

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	13574.82	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	130.41	100	j Factor	
Outlet Temperature (°F)	118.4512	124.4194	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	5740.1
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	331168.4
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	331168.4
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	13574.82	Tube-Side hi (BTU/hr·ft²·°F)	168.6431
Inlet Temperature (°F)	130.41	121.0124	j Factor	0.011561
Outlet Temperature (°F)	129.4309	125.012	Air-Side ho (BTU/hr·ft²·°F)	19.8098
Inlet Specific Humidity	0.020272		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity	0.020272		Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)	129.9204	123.0119		
Skin Temperature (°F)	127.6897	126.4444	U Overall (BTU/hr·ft²·°F)	5.639065
Velocity ***	5764.992	0.504613	Effective Area (ft²)	717.5125
Reynold's Number	1603.412	3757.927	LMTD	6.701516
Prandtl Number	0.726684	3.524269	Total Heat Transferred (BTU/hr)	27115
Bulk Visc (lbm/ft·hr)	0.048111	1.309111		
Skin Visc (lbm/ft·hr)		1.268623	Surface Effectiveness (Eta)	0.881565
Density (lbm/ft³)	0.06353	61.66439	Sensible Heat Transferred (BTU/hr)	27115
Cp (BTU/lbm·°F)	0.240245	0.998878	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015906	0.371029	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	13574.82	Tube-Side hi (BTU/hr·ft²·°F)	166.2351
Inlet Temperature (°F)	129.4309	119.7104	j Factor	0.011556
Outlet Temperature (°F)	128.4233	123.8268	Air-Side ho (BTU/hr·ft²·°F)	19.79955
Inlet Specific Humidity	0.020272		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity	0.020272		Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)	128.9271	121.7676		
Skin Temperature (°F)	126.6311	125.3501	U Overall (BTU/hr·ft²·°F)	5.597947
Velocity ***	5764.992	0.504452	Effective Area (ft²)	717.5125
Reynold's Number	1605.495	3714.764	LMTD	6.947216
Prandtl Number	0.726762	3.56911	Total Heat Transferred (BTU/hr)	27904.16
Bulk Visc (lbm/ft·hr)	0.048049	1.324322		
Skin Visc (lbm/ft·hr)		1.281303	Surface Effectiveness (Eta)	0.881617
Density (lbm/ft³)	0.063639	61.68406	Sensible Heat Transferred (BTU/hr)	27904.16
Cp (BTU/lbm·°F)	0.240245	0.998827	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015883	0.370619	Heat to Condensate (BTU/hr)	

PROTO-HX Report -- Extrapolation Calculation Output for Limiting Flow Case

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	13574.82	Tube-Side hi (BTU/hr·ft²·°F)	159.7789
Inlet Temperature (°F)	128.4233	115.6999	j Factor	0.01155
Outlet Temperature (°F)	127.1227	121.0124	Air-Side ho (BTU/hr·ft²·°F)	19.78764
Inlet Specific Humidity	0.020272		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity	0.020272		Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)	127.773	118.3564		
Skin Temperature (°F)	124.8119	123.1606	U Overall (BTU/hr·ft²·°F)	5.486089
Velocity ***	5764.992	0.50402	Effective Area (ft²)	717.5125
Reynold's Number	1607.926	3597.299	LMTD	9.149558
Prandtl Number	0.72685	3.696975	Total Heat Transferred (BTU/hr)	36015.75
Bulk Visc (lbm/ft·hr)	0.047976	1.367566		
Skin Visc (lbm/ft·hr)		1.307313	Surface Effectiveness (Eta)	0.881677
Density (lbm/ft³)	0.06378	61.73696	Sensible Heat Transferred (BTU/hr)	36015.75
Cp (BTU/lbm·°F)	0.240245	0.998816	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015857	0.369474	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	13574.82	Tube-Side hi (BTU/hr·ft²·°F)	157.263
Inlet Temperature (°F)	127.1227	114.4491	j Factor	0.011543
Outlet Temperature (°F)	125.8348	119.7104	Air-Side ho (BTU/hr·ft²·°F)	19.77428
Inlet Specific Humidity	0.020272		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity	0.020272		Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)	126.4788	117.0793		
Skin Temperature (°F)	123.5458	121.9112	U Overall (BTU/hr·ft²·°F)	5.440658
Velocity ***	5764.992	0.503862	Effective Area (ft²)	717.5125
Reynold's Number	1610.664	3553.652	LMTD	9.136426
Prandtl Number	0.726948	3.746789	Total Heat Transferred (BTU/hr)	35666.24
Bulk Visc (lbm/ft·hr)	0.047894	1.384363		
Skin Visc (lbm/ft·hr)		1.322552	Surface Effectiveness (Eta)	0.881745
Density (lbm/ft³)	0.063921	61.75638	Sensible Heat Transferred (BTU/hr)	35666.24
Cp (BTU/lbm·°F)	0.240245	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015828	0.369037	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	13574.82	Tube-Side hi (BTU/hr·ft²·°F)	148.0407
Inlet Temperature (°F)	125.8348	108.7745	j Factor	0.011535
Outlet Temperature (°F)	124.1394	115.6999	Air-Side ho (BTU/hr·ft²·°F)	19.75889
Inlet Specific Humidity	0.020272		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity	0.020272		Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)	124.9871	112.2375		
Skin Temperature (°F)	121.1303	118.9822	U Overall (BTU/hr·ft²·°F)	5.270737
Velocity ***	5764.992	0.503278	Effective Area (ft²)	717.5125
Reynold's Number	1613.838	3389.831	LMTD	12.41481
Prandtl Number	0.727058	3.945992	Total Heat Transferred (BTU/hr)	46950.58
Bulk Visc (lbm/ft·hr)	0.0478	1.451265		
Skin Visc (lbm/ft·hr)		1.359459	Surface Effectiveness (Eta)	0.881823
Density (lbm/ft³)	0.064106	61.828	Sensible Heat Transferred (BTU/hr)	46950.58
Cp (BTU/lbm·°F)	0.240245	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015795	0.367343	Heat to Condensate (BTU/hr)	

PROTO-HX Report -- Extrapolation Calculation Output for Limiting Flow Case

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	13574.82	Tube-Side hi (BTU/hr·ft²·°F)	145.8629
Inlet Temperature (°F)	124.1394	107.891	j Factor	0.011526
Outlet Temperature (°F)	122.5339	114.4491	Air-Side ho (BTU/hr·ft²·°F)	19.74187
Inlet Specific Humidity	0.020272		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity	0.020272		Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)	123.3372	111.1708		
Skin Temperature (°F)	119.6846	117.6518	U Overall (BTU/hr·ft²·°F)	5.228233
Velocity ***	5764.992	0.503153	Effective Area (ft²)	717.5125
Reynold's Number	1617.371	3354.1	LMTD	11.85177
Prandtl Number	0.727177	3.9922	Total Heat Transferred (BTU/hr)	44459.82
Bulk Visc (lbm/ft·hr)	0.047696	1.466726		
Skin Visc (lbm/ft·hr)		1.376791	Surface Effectiveness (Eta)	0.881909
Density (lbm/ft³)	0.064283	61.84335	Sensible Heat Transferred (BTU/hr)	44459.82
Cp (BTU/lbm·°F)	0.240245	0.998835	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015758	0.366962	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	13574.82	Tube-Side hi (BTU/hr·ft²·°F)	132.8281
Inlet Temperature (°F)	122.5339	100.0127	j Factor	0.011517
Outlet Temperature (°F)	120.3887	108.7745	Air-Side ho (BTU/hr·ft²·°F)	19.72252
Inlet Specific Humidity	0.020272		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity	0.020272		Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)	121.4612	104.3939		
Skin Temperature (°F)	116.5875	113.8776	U Overall (BTU/hr·ft²·°F)	4.967321
Velocity ***	5764.992	0.502391	Effective Area (ft²)	717.5125
Reynold's Number	1621.416	3130.16	LMTD	16.66772
Prandtl Number	0.727309	4.307462	Total Heat Transferred (BTU/hr)	59405.67
Bulk Visc (lbm/ft·hr)	0.047577	1.571659		
Skin Visc (lbm/ft·hr)		1.428014	Surface Effectiveness (Eta)	0.882007
Density (lbm/ft³)	0.064521	61.93712	Sensible Heat Transferred (BTU/hr)	59405.67
Cp (BTU/lbm·°F)	0.240245	0.998845	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.015716	0.364467	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110700.3	13574.82	Tube-Side hi (BTU/hr·ft²·°F)	131.7467
Inlet Temperature (°F)	120.3887	99.97818	j Factor	0.011506
Outlet Temperature (°F)	118.4512	107.891	Air-Side ho (BTU/hr·ft²·°F)	19.70147
Inlet Specific Humidity	0.020272		Tube Wall Resistance (hr·ft²·°F/BTU)	0.000247
Outlet Specific Humidity	0.020272		Overall Fouling (hr·ft²·°F/BTU)	0.031717
Average Temp (°F)	119.4199	103.9353		
Skin Temperature (°F)	115.0151	112.5682	U Overall (BTU/hr·ft²·°F)	4.943438
Velocity ***	5764.992	0.502342	Effective Area (ft²)	717.5125
Reynold's Number	1625.852	3115.201	LMTD	15.12588
Prandtl Number	0.727448	4.330242	Total Heat Transferred (BTU/hr)	53651.18
Bulk Visc (lbm/ft·hr)	0.047447	1.579206		
Skin Visc (lbm/ft·hr)		1.446526	Surface Effectiveness (Eta)	0.882114
Density (lbm/ft³)	0.064737	61.94322	Sensible Heat Transferred (BTU/hr)	53651.18

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Cp (BTU/lbm·°F)	0.240245	0.998908	Latent Heat Transferred (BTU/hr)
K (BTU/hr·ft·°F)	0.01567	0.364294	Heat to Condensate (BTU/hr)

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 1)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 24.14444854
Ao (ft^2) = 717.5125349
Ao/Ai = 29.71749526
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 20
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 8.75
UL/L (%) = 0.24
UL(ft) = 0.021

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.11225
Uhfin/hfin (%) = 1.48
Uhfin (ft) = 0.0016613

Mdotc* (lbm/hr) = 13574.82245
Q* (Ft^3/hr) = 220.1403767
DT* (DegF) = 3.999648762
rho* (lbm/ft^3) = 61.66439186
Urho*/rho* (%) = 2
Urho* = 1.233287837

Cp* (Btu/lbm/DegF) = 0.998878349
UCp*/Cp* (%) = 2
UCp* = 0.019977567

q* (Btu/hr) = 27115.00023
LMTD* (DegF) = 6.70151565
Uo* = 5.63906478
R* = (1/Uo*) = 0.17733437
Rf [(hr-DegF-ft^2)/Btu] = 0.031717495
Etas = 0.881584535
ho* [Btu/(hr-DegF-ft^2)] = 19.80979838
ho*(eff) [Btu/(hr-DegF-ft^2)] = 17.4636157
Uho*/ho* (%) = 15
Uho* = 2.619542355

hi* [Btu/(hr-DegF-ft^2)] = 168.6431095
Uhi*/hi* (%) = 15
Uhi* = 25.29646643

Rw* [(hr-DegF-ft^2)/Btu] = 0.000247317
URw*/Rw* (%) = 2
URw* = 4.94634E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 1)

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
717.51253	0.05208	0.00417	8.75000	0.02100	0.00100	0.00004	0.11225	0.00166	0.04877	34.99475
Derivatives:	-5904.62		82.00		7938.80		14942.99			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.17733	17.46362	2.61954	168.64311	25.29647	0.00025	0.00000	0.03172	0.00000	0.15673	0.02779

6 Analytical Uncertainty in Extrapolated Heat Transfer

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
27115.0002	0.17733	0.02779	717.51253	34.99475	6.70152	0.16414	4450.63334

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 2)

I. PROTO-HX Output -- Fouling Calculation

[redacted]

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 24.14444854
Ao (ft^2) = 717.5125349
Ao/Ai = 29.71749526
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 20
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 8.75
UL/L (%) = 0.24
UL(ft) = 0.021

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.11225
Uhfin/hfin (%) = 1.48
Uhfin (ft) = 0.0016613

Mdotc* (lbm/hr) = 13574.82245
Q* (Ft^3/hr) = 220.0701758
DT* (DegF) = 4.116450935
rho* (lbm/ft^3) = 61.68406238
Urho*/rho* (%) = 2
Urho* = 1.233681248

Cp* (Btu/lbm/DegF) = 0.998826811
UCp*/Cp* (%) = 2
UCp* = 0.019976536

q* (Btu/hr) = 27904.16465
LMTD* (DegF) = 6.947215729
Uo* = 5.59794654
R* = (1/Uo*) = 0.178636933
Rf [(hr-DegF-ft^2)/Btu] = 0.031717495
Etas = 0.881616503
ho* [Btu/(hr-DegF-ft^2)] = 19.79954617
ho*(eff) [Btu/(hr-DegF-ft^2)] = 17.45560666
Uho*/ho* (%) = 15
Uho* = 2.618340999

hi* [Btu/(hr-DegF-ft^2)] = 166.2350989
Uhi*/hi* (%) = 15
Uhi* = 24.93526483

Rw* [(hr-DegF-ft^2)/Btu] = 0.000247317
URw*/Rw* (%) = 2
URw* = 4.94634E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 2)

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
717.51253	0.05208	0.00417	8.75000	0.02100	0.00100	0.00004	0.11225	0.00166	0.04877	34.99475
Derivatives:	-5904.62		82.00		7938.80		14942.99			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.17864	17.45561	2.61834	166.23510	24.93526	0.00025	0.00000	0.03172	0.00000	0.15763	0.02816

6 Analytical Uncertainty in Extrapolated Heat Transfer

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
27904.1646	0.17864	0.02816	717.51253	34.99475	6.94722	0.16500	4604.25253

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Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 3)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 24.14444854
Ao (ft^2) = 717.5125349
Ao/Ai = 29.71749526
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 20
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 8.75
UL/L (%) = 0.24
UL(ft) = 0.021

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.11225
Uhfin/hfin (%) = 1.48
Uhfin (ft) = 0.0016613

Mdotc* (lbm/hr) = 13574.82245
Q* (Ft^3/hr) = 219.8815972
DT* (DegF) = 5.312449781
rho* (lbm/ft^3) = 61.73696492
Urho*/rho* (%) = 2
Urho* = 1.234739298

Cp* (Btu/lbm/DegF) = 0.998815769
UCp*/Cp* (%) = 2
UCp* = 0.019976315

q* (Btu/hr) = 36015.74715
LMTD* (DegF) = 9.149558111
Uo* = 5.48608859
R* = (1/Uo*) = 0.182279229
Rf [(hr-DegF-ft^2)/Btu] = 0.031717495
Etas = 0.881676887
ho* [Btu/(hr-DegF-ft^2)] = 19.78763579
ho*(eff) [Btu/(hr-DegF-ft^2)] = 17.44630111
Uho*/ho* (%) = 15
Uho* = 2.816945167

hi* [Btu/(hr-DegF-ft^2)] = 159.7789068
Uhi*/hi* (%) = 15
Uhi* = 23.96683602

Rw* [(hr-DegF-ft^2)/Btu] = 0.000247317
URw*/Rw* (%) = 2
URw* = 4.94634E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 3)

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
717.51253	0.05208	0.00417	8.75000	0.02100	0.00100	0.00004	0.11225	0.00166	0.04877	34.99475
Derivatives:	-5904.62		82.00		7938.80		14942.99			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.18228	17.44630	2.61695	159.77891	23.96684	0.00025	0.00000	0.03172	0.00000	0.16016	0.02919

6 Analytical Uncertainty in Extrapolated Heat Transfer

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
36015.7472	0.18228	0.02919	717.51253	34.99475	9.14956	0.16742	6029.74516

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 4)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 24.14444854
Ao (ft^2) = 717.5125349
Ao/Ai = 29.71749526
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 20
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 8.75
UL/L (%) = 0.24
UL(ft) = 0.021

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.11225
Uhfin/hfin (%) = 1.48
Uhfin (ft) = 0.0016613

Mdotc* (lbm/hr) = 13574.82245
Q* (Ft^3/hr) = 219.8124741
DT* (DegF) = 5.261267413
rho* (lbm/ft^3) = 61.75637898
Urho*/rho* (%) = 2
Urho* = 1.23512758

Cp* (Btu/lbm/DegF) = 0.998799534
UCp*/Cp* (%) = 2
UCp* = 0.019975991

q* (Btu/hr) = 35666.2354
LMTD* (DegF) = 9.13642647
Uo* = 5.440657858
R* = (1/Uo*) = 0.183801302
Rf [(hr-DegF-ft^2)/Btu] = 0.031717495
Etas = 0.881744607
ho* [Btu/(hr-DegF-ft^2)] = 19.77428085
ho*(eff) [Btu/(hr-DegF-ft^2)] = 17.43586549
Uho*/ho* (%) = 15
Uho* = 2.615379823

hi* [Btu/(hr-DegF-ft^2)] = 157.2629764
Uhi*/hi* (%) = 15
Uhi* = 23.58944645

Rw* [(hr-DegF-ft^2)/Btu] = 0.000247317
URw*/Rw* (%) = 2
URw* = 4.94634E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 4)

1 **Analytical Uncertainty in Heat Transfer Surface Area**

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
717.51253	0.05208	0.00417	8.75000	0.02100	0.00100	0.00004	0.11225	0.00166	0.04877	34.99475
Derivatives:	-5904.62		82 00		7938.80		14942.99			

2 **Analytical Uncertainty in Test Heat Transfer Rate**

[redacted]

3 **Analytical Uncertainty in Observed Heat Transfer Resistance (R):**

[redacted]

4 **Analytical Uncertainty in Observed Rf**

[redacted]

5 **Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:**

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.18380	17.43587	2.61538	157.26298	23.58945	0.00025	0.00000	0.03172	0.00000	0.16116	0.02962

6 **Analytical Uncertainty in Extrapolated Heat Transfer**

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
35666.2354	0.18380	0.02962	717.51253	34.99475	9.13643	0.16838	6005.49693

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 5)

I. PROTO-HX Output -- Fouling Calculation

[redacted]

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 24 14444854
Ao (ft^2) = 717.5125349
Ao/Ai = 29.71749526
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 20
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 8.75
UL/L (%) = 0.24
UL(ft) = 0.021

tfin (ft) = 0.001
Utfin/tfin (%) = 4 17
Utfin (ft) = 0.0000417

hfin (ft) = 0.11225
Uhfin/hfin (%) = 1.48
Uhfin (ft) = 0.0016613

Mdotc* (lbm/hr) = 13574.82245
Q* (Ft^3/hr) = 219.5578482
DT* (DegF) = 6.925433746
rho* (lbm/ft^3) = 61.82799915
Urho*/rho* (%) = 2
Urho* = 1.236559983

Cp* (Btu/lbm/DegF) = 0.998799978
UCp*/Cp* (%) = 2
UCp* = 0.019976

q* (Btu/hr) = 46950.58376
LMTD* (DegF) = 12.41481174
Uo* = 5.270737233
R* = (1/Uo*) = 0.189726779
Rf [(hr-DegF-ft^2)/Btu] = 0.031717495
Etas = 0 881822687
ho* [Btu/(hr-DegF-ft^2)] = 19.75889016
ho*(eff) [Btu/(hr-DegF-ft^2)] = 17.42383722
Uho*/ho* (%) = 15
Uho* = 2.613575582

hi* [Btu/(hr-DegF-ft^2)] = 148.04072
Uhi*/hi* (%) = 15
Uhi* = 22.206108

Rw* [(hr-DegF-ft^2)/Btu] = 0.000247317
URw*/Rw* (%) = 2
URw* = 4 94634E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 5)

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
717.51253	0.05208	0.00417	8.75000	0.02100	0.00100	0.00004	0.11225	0.00166	0.04877	34.99475
Derivatives:	-5904.62		82.00		7938.80		14942.99			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.18973	17.42384	2.61358	148.04072	22.20611	0.00025	0.00000	0.03172	**0.00000**	0.16507	0.03132

6 Analytical Uncertainty in Extrapolated Heat Transfer

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
46950.5838	0.18973	0.03132	717.51253	34.99475	12.41481	0.17212	8081.13244

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 6)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =	[redacted]
Ai (ft^2) =	[redacted]
Ao (ft^2) =	[redacted]
Ao/Ai =	[redacted]
do (ft) =	[redacted]
Udo/do (%) =	[redacted]
Udo (ft) =	[redacted]
Nt =	[redacted]
Nl =	[redacted]
Lambda (fins/ft) =	[redacted]
L (ft) =	[redacted]
UL/L (%) =	[redacted]
UL(ft) =	[redacted]
tfin (ft) =	[redacted]
Utfin/tfin (%) =	[redacted]
Utfin (ft) =	[redacted]
hfin (ft) =	[redacted]
Uhfin/hfin (%) =	[redacted]
Uhfin (ft) =	[redacted]
Mdotc (lbm/hr) =	[redacted]
Q (Ft^3/hr) =	[redacted]
DT (DegF) =	[redacted]
rho (lbm/ft^3) =	[redacted]
Urho/rho (%) =	[redacted]
Urho =	[redacted]
Cp (Btu/lbm/DegF) =	[redacted]
UCp/Cp (%) =	[redacted]
UCp =	[redacted]
q (Btu/hr) =	[redacted]
LMTD (DegF) =	[redacted]
Uo =	[redacted]
R = (1/Uo) =	[redacted]
Rf [(hr-DegF-ft^2)/Btu] =	[redacted]
Etas =	[redacted]
ho [Btu/(hr-DegF-ft^2)] =	[redacted]
ho(eff) [Btu/(hr-DegF-ft^2)] =	[redacted]
Uho/ho (%) =	[redacted]
Uho =	[redacted]
hi [Btu/(hr-DegF-ft^2)] =	[redacted]
Uhi/hi (%) =	[redacted]
Uhi =	[redacted]
Rw [(hr-DegF-ft^2)/Btu] =	[redacted]
URw/Rw (%) =	[redacted]
URw =	[redacted]

II. PROTO-HX Output – Extrapolation Calculation

di (ft) =	0.043916667
Ai (ft^2) =	24.14444854
Ao (ft^2) =	717.5125349
Ao/Ai =	29.71749526
do (ft) =	0.052083333
Udo/do (%) =	8
Udo (ft) =	0.004166667
Nt =	20
Nl =	2
Lambda (fins/ft) =	120
L (ft) =	8.75
UL/L (%) =	0.24
UL(ft) =	0.021
tfin (ft) =	0.001
Utfin/tfin (%) =	4.17
Utfin (ft) =	0.0000417
hfin (ft) =	0.11225
Uhfin/hfin (%) =	1.48
Uhfin (ft) =	0.0016613
Mdotc* (lbm/hr) =	13574.82245
Q* (Ft^3/hr) =	219.5033609
DT* (DegF) =	6.558117613
rho* (lbm/ft^3) =	61.8433467
Urho*/rho* (%) =	2
Urho* =	1.236866934
Cp* (Btu/lbm/DegF) =	0.998835078
UCp*/Cp* (%) =	2
UCp* =	0.019976702
q* (Btu/hr) =	44459.81549
LMTD* (DegF) =	11.85177138
Uo* =	5.22823257
R* = (1/Uo*) =	0.191269227
Rf [(hr-DegF-ft^2)/Btu] =	0.031717495
Etas =	0.88190901
ho* [Btu/(hr-DegF-ft^2)] =	19.74187056
ho*(eff) [Btu/(hr-DegF-ft^2)] =	17.41053353
Uho*/ho* (%) =	15
Uho* =	2.61158003
hi* [Btu/(hr-DegF-ft^2)] =	145.8628733
Uhi*/hi* (%) =	15
Uhi* =	21.879431
Rw* [(hr-DegF-ft^2)/Btu] =	0.000247317
URw*/Rw* (%) =	2
URw* =	4.94634E-06

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Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 6)

1 **Analytical Uncertainty in Heat Transfer Surface Area**

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
717.51253	0.05208	0.00417	8.75000	0.02100	0.00100	0.00004	0.11225	0.00166	0.04877	34.99475
Derivatives:	-5904.62		82.00		7938.80		14942.99			

2 **Analytical Uncertainty in Test Heat Transfer Rate**

[redacted]

3 **Analytical Uncertainty in Observed Heat Transfer Resistance (R):**

[redacted]

4 **Analytical Uncertainty in Observed Rf**

[redacted]

5 **Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:**

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.19127	17.41053	2.61158	145.86287	21.87943	0.00025	0.00000	0.03172	0.00000	0.16600	0.03175

6 **Analytical Uncertainty in Extrapolated Heat Transfer**

q*	R*.	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
44459.8155	0.19127	0.03175	717.51253	34.99475	11.85177	0.17302	7692.48427

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 7)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 24.14444854
Ao (ft^2) = 717.5125349
Ao/Ai = 29.71749526
do (ft) = 0.052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 20
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 8.75
UL/L (%) = 0.24
UL(ft) = 0.021

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.11225
Uhfin/hfin (%) = 1.48
Uhfin (ft) = 0.0016613

Mdotc* (lbm/hr) = 13574.82245
Q* (Ft^3/hr) = 219.1710457
DT* (DegF) = 8.761814629
rho* (lbm/ft^3) = 61.93711587
Urho*/rho* (%) = 2
Urho* = 1.238742317

Cp* (Btu/lbm/DegF) = 0.998845442
UCp*/Cp* (%) = 2
UCp* = 0.019976909

q* (Btu/hr) = 59405.67138
LMTD* (DegF) = 16.66771848
Uo* = 4.96732138
R* = (1/Uo*) = 0.201315744
Rf [(hr-DegF-ft^2)/Btu] = 0.031717495
Etas = 0.8820072
ho* [Btu/(hr-DegF-ft^2)] = 19.72252126
ho*(eff) [Btu/(hr-DegF-ft^2)] = 17.39540576
Uho*/ho* (%) = 15
Uho* = 2.609310864

hi* [Btu/(hr-DegF-ft^2)] = 132.8281006
Uhi*/hi* (%) = 15
Uhi* = 19.92421509

Rw* [(hr-DegF-ft^2)/Btu] = 0.000247317
URw*/Rw* (%) = 2
URw* = 4.94634E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 7)

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
717.51253	0.05208	0.00417	8.75000	0.02100	0.00100	0.00004	0.11225	0.00166	0.04877	34.99475
Derivatives:	-5904.62		82.00		7938.80		14942.99			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R*	ho*	Uho*	hi*	Uhi*	Rw*	URw*	Rf	URf	UR*/R*	UR*
0.20132	17.39541	2.60931	132.82810	19.92422	0.00025	0.00000	0.03172	**0.00000**	0.17212	0.03465

6 Analytical Uncertainty in Extrapolated Heat Transfer

q*	R*	UR*	Ao	UAo	LMTD*	Uq*/q*	Uq*
59405.6714	0.20132	0.03465	717.51253	34.99475	16.66772	0.17889	10627.19473

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate
(Row 8)

I. PROTO-HX Output -- Fouling Calculation

di (ft) =
Ai (ft^2) =
Ao (ft^2) =
Ao/Ai =
do (ft) =
Udo/do (%) =
Udo (ft) =

Nt =
Nl =
Lambda (fins/ft) =
L (ft) =
UL/L (%) =
UL(ft) =

tfin (ft) =
Utfin/tfin (%) =
Utfin (ft) =

hfin (ft) =
Uhfin/hfin (%) =
Uhfin (ft) =

Mdotc (lbm/hr) =
Q (Ft^3/hr) =
DT (DegF) =
rho (lbm/ft^3) =
Urho/rho (%) =
Urho =

Cp (Btu/lbm/DegF) =
UCp/Cp (%) =
UCp =

q (Btu/hr) =
LMTD (DegF) =
Uo =
R = (1/Uo) =
Rf [(hr-DegF-ft^2)/Btu] =
Etas =
ho [Btu/(hr-DegF-ft^2)] =
ho(eff) [Btu/(hr-DegF-ft^2)] =
Uho/ho (%) =
Uho =

hi [Btu/(hr-DegF-ft^2)] =
Uhi/hi (%) =
Uhi =

Rw [(hr-DegF-ft^2)/Btu] =
URw/Rw (%) =
URw =

[redacted]

II. PROTO-HX Output -- Extrapolation Calculation

di (ft) = 0.043916667
Ai (ft^2) = 24.14444854
Ao (ft^2) = 717.5125349
Ao/Ai = 29 71749526
do (ft) = 0 052083333
Udo/do (%) = 8
Udo (ft) = 0.004166667

Nt = 20
Nl = 2
Lambda (fins/ft) = 120
L (ft) = 8.75
UL/L (%) = 0.24
UL(ft) = 0.021

tfin (ft) = 0.001
Utfin/tfin (%) = 4.17
Utfin (ft) = 0.0000417

hfin (ft) = 0.11225
Uhfin/hfin (%) = 1.48
Uhfin (ft) = 0.0016613

Mdotc* (lbm/hr) = 13574.82245
Q* (Ft^3/hr) = 219.1494381
DT* (DegF) = 7.912798719
rho* (lbm/ft^3) = 61.94322271
Urho*/rho* (%) = 2
Urho* = 1.238864454

Cp* (Btu/lbm/DegF) = 0.998908141
UCp*/Cp* (%) = 2
UCp* = 0.019978163

q* (Btu/hr) = 53651.18089
LMTD* (DegF) = 15.12588275
Uo* = 4 943437676
R* = (1/Uo*) = 0.20228838
Rf [(hr-DegF-ft^2)/Btu] = 0.031717495
Etas = 0.882114054
ho* [Btu/(hr-DegF-ft^2)] = 19.70147117
ho*(eff) [Btu/(hr-DegF-ft^2)] = 17.3789446
Uho*/ho* (%) = 15
Uho* = 2.606841689

hi* [Btu/(hr-DegF-ft^2)] = 131.7467215
Uhi*/hi* (%) = 15
Uhi* = 19.76200823

Rw* [(hr-DegF-ft^2)/Btu] = 0.000247317
URw*/Rw* (%) = 2
URw* = 4.94634E-06

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate (Row 8)

1 Analytical Uncertainty in Heat Transfer Surface Area

Ao	Do	Ud	L	UL	tfin	Utfin	hfin	Uhfin	UAo/Ao	UAo
717.51253	0.05208	0.00417	8.75000	0.02100	0.00100	0.00004	0.11225	0.00166	0.04877	34.99475
Derivatives:	-5904.62		82.00		7938.80		14942.99			

2 Analytical Uncertainty in Test Heat Transfer Rate

[redacted]

3 Analytical Uncertainty in Observed Heat Transfer Resistance (R):

[redacted]

4 Analytical Uncertainty in Observed Rf

[redacted]

5 Analytical Uncertainty in Overall Extrapolation Heat Transfer Resistance:

R^*	ho^*	Uho^*	hi^*	Uhi^*	Rw^*	URw^*	Rf	URf	UR^*/R^*	UR^*
0.20229	17.37894	2.60684	131.74672	19.76201	0.00025	0.00000	0.03172	**0.00000**	0.17262	0.03492

6 Analytical Uncertainty in Extrapolated Heat Transfer

q^*	R^*	UR^*	Ao	UAo	$LMTD^*$	Uq^*/q^*	Uq^*
53651.1809	0.20229	0.03492	717.51253	34.99475	15 12588	0.17937	9623.65803

Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate

	Extrapolated Heat Transfer (Btu/hr)	Calculated Uncertainty (Btu/hr)	(Uq/q)^2
Row1	27115.0002	4450.6333	0.000181
Row2	27904.1646	4604.2525	0.000193
Row3	36015.7472	6029.7452	0.000332
Row4	35666.2354	6005.4969	0.000329
Row5	46950.5838	8081.1324	0.000595
Row6	44459.8155	7692.4843	0.000540
Row7	59405.6714	10627.1947	0.001030
Row8	53651.1809	9623.6580	0.000844
	331168.3989	**21058.5416**	**0.063589**
	qtot	**SRSS**	**SRSS**

Uqtot/qtot = **6.36%**

(66.5 gpm Case)

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Analytical Uncertainty Calculation for Extrapolation Heat Transfer Rate

	Extrapolated Heat Transfer (Btu/hr)	Calculated Uncertainty (Btu/hr)	(Uq/q)^2
Row1	70294.7986	8445.3499	0.000381
Row2	63265.8492	7611.4575	0.000309
Row3	61001.3988	7353.9743	0.000289
Row4	53941.6362	6510.6279	0.000226
Row5	53234.1862	6439.2884	0.000221
Row6	45755.0059	5539.4034	0.000164
Row7	46831.9924	5683.3513	0.000172
Row8	38456.5123	4668.8780	0.000116
	432781.3794	**18761.0171**	**0.043350**
	qtot	**SRSS**	**SRSS**

Uqtot/qtot = **4.33%**

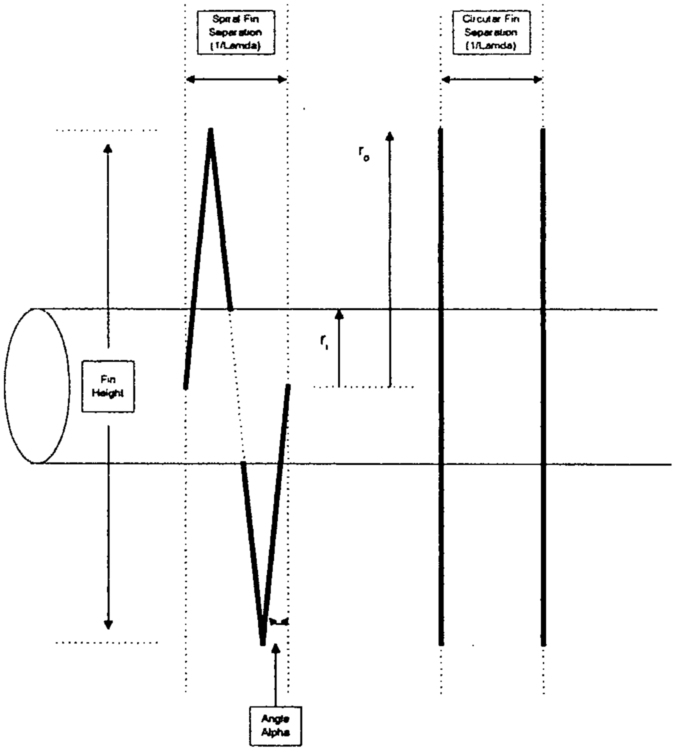
(200 gpm Case)

Attachment K to
Proto-Power Calculation
97-198
Revision A

COMPARING SPIRAL AND CIRCULAR FINS

Area Calculation

A view of the spiral fin layout as compared to the circular fin layout is provided below. Let angle α represent the angle between the plane of the circular fin and the plane of the spiral fin.



A differential area in the circular fin is given as:

$dA = rdrd\theta$

The expression for circular fin surface area (times 2 for both sides and disregarding the edge area) taken over a complete traverse of the tube is given as:

$$A_{cf} = 2\int_{ri}^{ro}\int_{0}^{2\pi} rdrd\theta = 2\pi(r_o^2 - r_i^2)$$

Where:

r_o = the fin outside radius which is one half the fin height

r_i = the inside fin radius which is the tube outside radius

The spiral fin surface area (times 2 for both sides and disregarding the edge area) can be approximated by the expression:

$$A_{sf} = \left(\frac{1}{\cos\alpha}\right)2\pi(r_o^2 - r_i^2)$$

The ratio of the two areas becomes:

$$\frac{A_{sf}}{A_{cf}} = \left(\frac{1}{\cos\alpha}\right)$$

Angle α is approximated by the expression:

$$\tan\alpha = \frac{\frac{1}{4}(\text{fin separation})}{r_o} = \frac{1}{4r_o\lambda}$$

$$\alpha = \tan^{-1}\left(\frac{1}{4r_o\lambda}\right)$$

where:

λ = fin pitch

Substituting fin height into the expression yields the following:

$$\alpha = \tan^{-1}\left(\frac{2}{4H_f\lambda}\right) = \tan^{-1}\left(\frac{1}{2H_f\lambda}\right)$$

As the angle α goes to zero, the spiral fin area approaches that of the circular fin. It can be seen that for very small fin separations (i.e., high fin pitch) the smaller the resulting angle α.

For the case of the VY cooler fin geometry:

$$\alpha = \tan^{-1}\left(\frac{1}{2H_f\lambda}\right) = \tan^{-1}\left(\frac{1}{2(1.487)(10)}\right) = \tan^{-1}(0.033625) = 1.93^\circ$$

The resulting area ratio is then:

$$\frac{A_{sf}}{A_{cf}} = \left(\frac{1}{\cos\alpha}\right) = \left(\frac{1}{\cos(1.93^\circ)}\right) = 1.00057$$

This difference is negligible and is bounded by the uncertainty in the analysis presented in Attachment J.

<u>Heat Transfer Coefficient</u>

The fin geometry affects the calculation of the outside heat transfer film coefficient (h_o) for condensing modes of operation. Vertical (circular) fins provide for better condensation heat transfer since the condensate falls away from the fins at a faster rate than if the fin were inclined (i.e., spiral geometry). As shown in the area discussion above, the angular difference between the circular fin geometry and the spriral fin geometry for the VY coils with a fin pitch of 10 fins per inch is very small (i.e., <2°). The angle of incline, therefore, is deemed to be sufficiently small as to make the difference between circular and spiral fin geometries negligible even for condensing modes of operation. In other words, as far as condensation removal from the fin surfaces is concerned, the 10 fin per inch fin pitch of the VY coils results in a fin orientation that is sufficiently close to vertical as to make differences in condensation heat transfer predictions negligible.

Attachment L to
Proto-Power Calculation
97-198
Revision A

COMED NUCLEAR DESIGN INFORMATION TRANSMITTAL

☒ SAFETY-RELATED
☐ NON-SAFETY-RELATED
☐ REGULATORY RELATED

Originating Organization
Section: SE
Company: ComEd

NDIT No.: LS-0847
Upgrade: 0
Page 1 of 2

Station: LaSalle County Units: 1,2
Design Change Authority No N/A

System: VY

To: P hilpot, Lloyd. Proto-Power

Subject:
Dimensional Verification for Tubing and Fins for Coolers 1(2)VY03A and 1(2)VY04A.

Miller, William J. Preparer:	System Engineer Position:	William Signature:	7/6/98 Date
Friedrich, Rich Reviewer:	Engineer Position:	Rich Friedrich Signature:	7/6/98 Date
hall, Rich Approver:	DE- Mech. Supv. Position:	Richard Hall Signature:	7/6/98 Date

Status of Information: ☒ Approved for Use ☐ Unverified ☐ Engineering Judgement

Verification Method N/A
Schedule:

Purpose of Issuance

Transmittal of Dimensions to Proto-Power for Heat Exchanger analysis.

Source of Information

Walkdown performed on the 2VY03A and 2VY04A coolers performed by W. Miller (System Engineering) and R. Friedrick (Design Engineering) on 7/3/98.

Description of Information

The following measurements were obtained for the 2VY03A and 2VY04A room coolers at the request of Proto-Power Corporation. These conditions were obtained at ambient conditions with the systems shutdown. Attached is a copy of a sketch for each cooler that provides dimensions obtained in the field.

The following information was obtained for the 2VY03A cooler
Tube outside diameter: 0.672 inches
Fin Height: 1.452 inches
Transverse Tube Pitch: 1.410 Inches
Effective Finned Tube Length: 108 inches (dimension is based on 111 inches from the inside of the furthest separated tube support "end" plates, which includes three - 1 inch tube support plates between the end plates).

The following information was obtained for the 2VY04A cooler

Distribution: SEAG
Szumski, Daniel R. - ComEd, SES-BOP
Wilhelmsen, George R. - ComEd, SES-BOP

COMED NUCLEAR DESIGN INFORMATION TRANSMITTAL

☒ SAFETY-RELATED	Originating Organization	**NDIT No.:** LS-0847
☐ NON-SAFETY-RELATED	Section: SE	Upgrade: 0
☐ REGULATORY RELATED	Company: ComEd	Page 2 of 2

Tube outside diameter:	0.675 inches
Fin Height:	1.347 inches
Transverse Tube Pitch:	1.370 inches

Effective Finned Tube Length: 105 inches (dimension is based on 108 inches from the inside of the furthest separated tube support "end" plates, which include three - 1 inch tube support plates between the end plates).

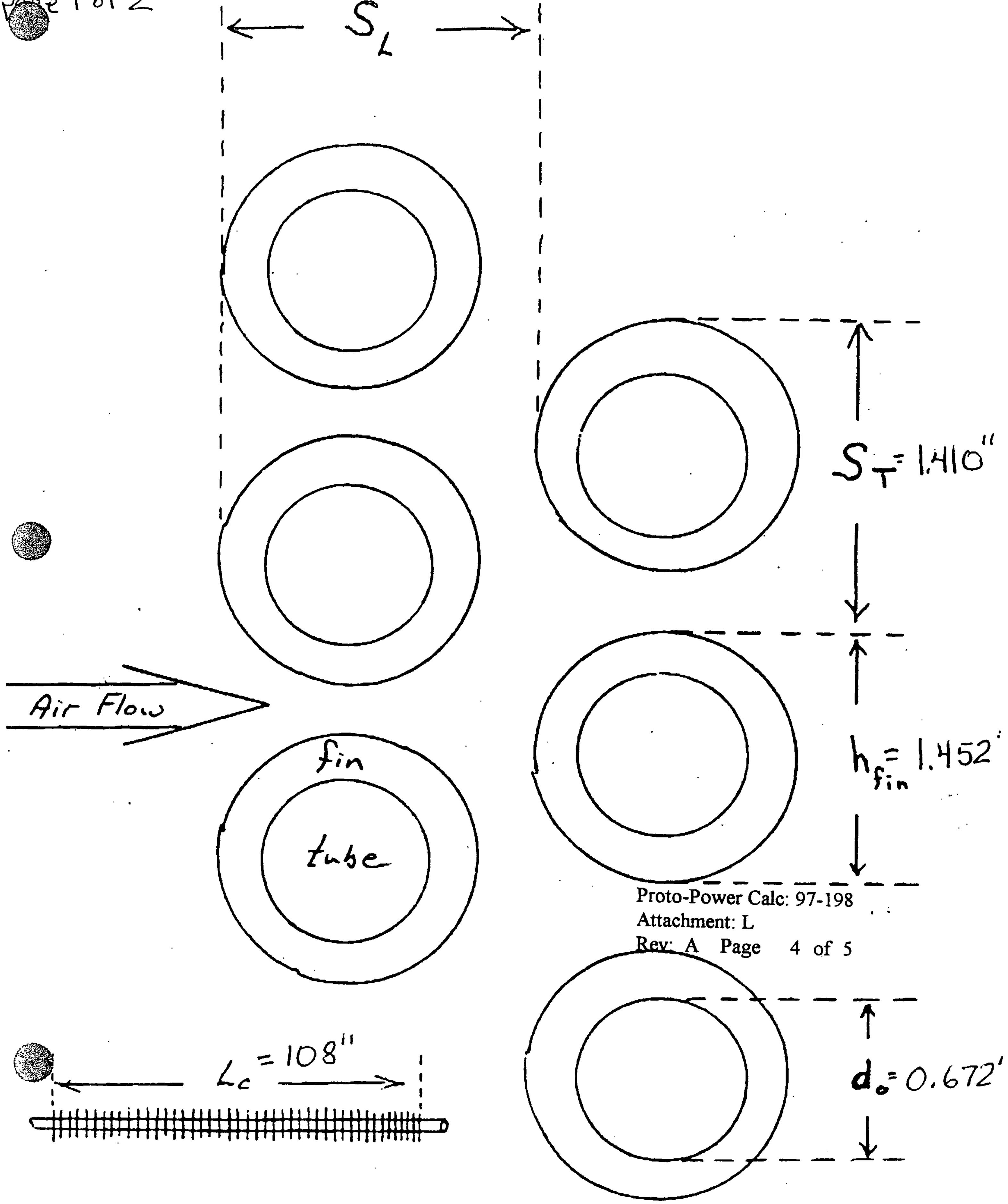
The first three measurement for each cooler were taken with a calibrated set of calipers (MMD Id No 7140, calibration due 2/99). The Effective Finned Tube Length was taken with a metal tape measure. The uncertainities for these measurements are based on engineering best estimates for the measurement techiniques used and are as stated in NDIT LS-0835 dated 6/19/98. Each cooler appeared to have staggered rows of tubes. The transverse tube pitch was variable for the various individual fins and the above dimension is considered typical.

Attachment 1 contains two sheets with sketches of the identical dimensions provided above.

NDIT LS-0847, Page 2 of 2 end. Attached - 2 pages of sketch.

JDIT LS-0847
Attachment 1
Page 1 of 2

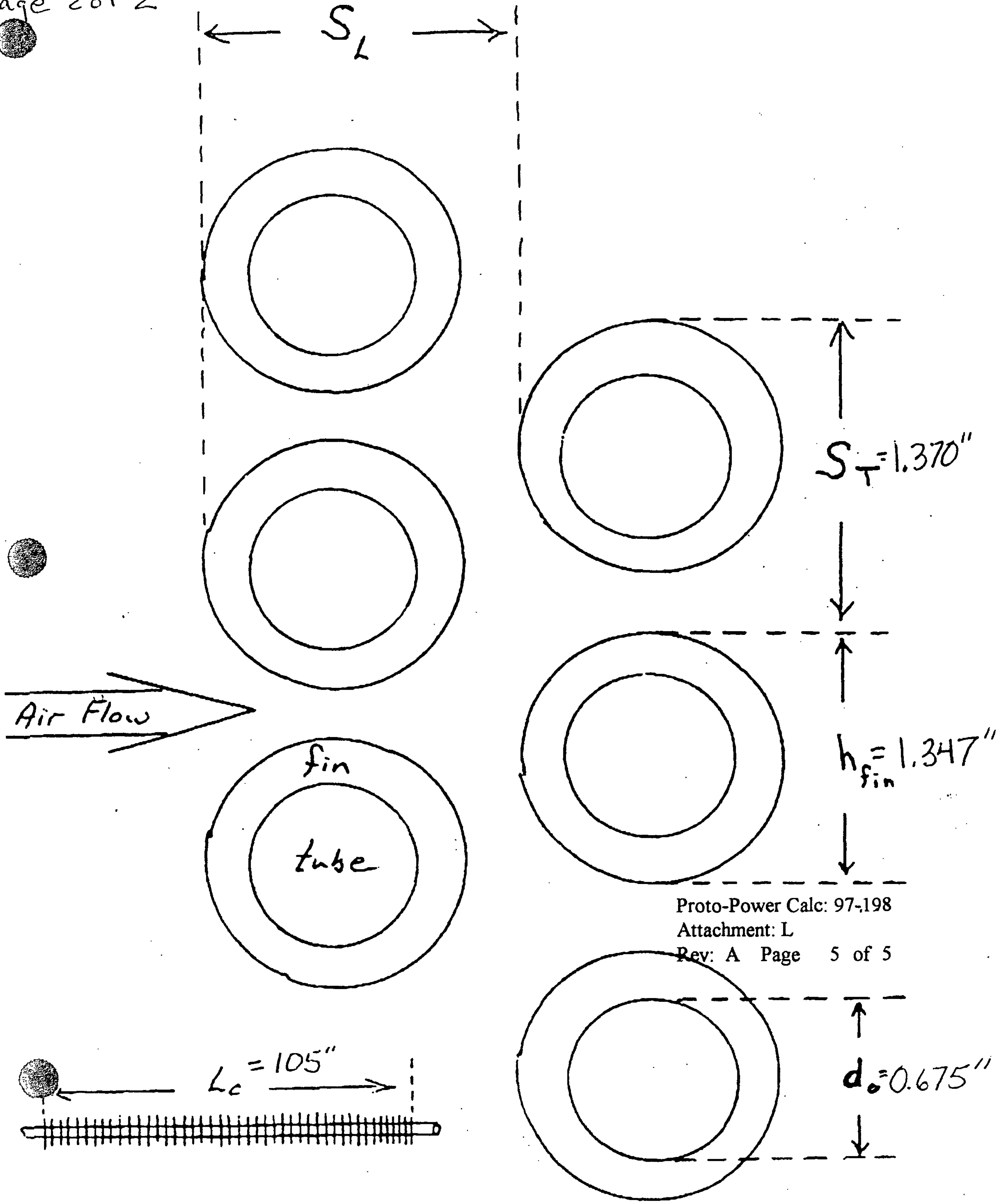
2VY03A



Proto-Power Calc: 97-198
Attachment: L
Rev: A Page 4 of 5

DIT LS-0847
Attachment 1
Page 2 of 2

2VY04A



Proto-Power Calc: 97-198
Attachment: L
Rev: A Page 5 of 5

Attachment M to
Proto-Power Calculation
97-198
Revision A

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	33,546.00 acfm	118.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	←
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle VY Cooler 04A
	j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils
Fouling Sensitivity (Tube f = 0.0000)

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	39.20
Air Flow (acfm)	30,048.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

18:40:27 **PROTO-HX 3.01 by Proto-Power Corporation (SN#PHX-0000)** 07/10/98

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

Fouling Sensitivity (Tube f = 0.0000)

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	111,037.50	19,492.05	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	128.40	127.96	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.00200000
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	2,870.05
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	544,475
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	544,475
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	111,037.50	19,492.05	Tube-Side hi (BTU/hr·ft^2·°F)	281.44
Inlet Temperature (°F)	148.00	115.91	j Factor	0.0105
Outlet Temperature (°F)	143.15	129.74	Air-Side ho (BTU/hr·ft^2·°F)	18.13
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.00200000
Average Temp (°F)	145.58	122.82		
Skin Temperature (°F)	133.53	133.09	U Overall (BTU/hr·ft^2·°F)	8.55
Velocity ***	5,782.55	0.72	Effective Area (ft^2)	717.51
Reynold's Number	2,102	5,387	LMTD	21.96
Prandtl Number	0.7253	3.5310	Total Heat Transferred (BTU/hr)	134,672
Bulk Visc (lbm/ft·hr)	0.0491	1.3114		
Skin Visc (lbm/ft·hr)		1.1959	Surface Effectiveness (Eta)	0.8902
Density (lbm/ft^3)	0.0621	61.6674	Sensible Heat Transferred (BTU/hr)	134,672
Cp (BTU/lbm·°F)	0.2402	0.9990	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3710	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

Fouling Sensitivity (Tube f = 0.0000)

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	111,037.50	19,492.05
Inlet Temperature (°F)	143.15	113.54
Outlet Temperature (°F)	138.72	126.18
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	140.94	119.86
Skin Temperature (°F)	129.91	129.51
Velocity ***	5,782.55	0.72
Reynold's Number	2,114	5,239
Prandtl Number	0.7258	3.6397
Bulk Visc (lbm/ft·hr)	0.0488	1.3482
Skin Visc (lbm/ft·hr)		1.2342
Density (lbm/ft³)	0.0625	61.7138
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0162	0.3700

Tube-Side hi (BTU/hr·ft²·°F)	273.39
j Factor	0.0105
Air-Side ho (BTU/hr·ft²·°F)	18.08
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.00200000
U Overall (BTU/hr·ft²·°F)	8.42
Effective Area (ft²)	717.51
LMTD	20.37
Total Heat Transferred (BTU/hr)	123,101
Surface Effectiveness (Eta)	0.8904
Sensible Heat Transferred (BTU/hr)	123,101
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	111,037.50	19,492.05
Inlet Temperature (°F)	138.72	99.99
Outlet Temperature (°F)	133.14	115.91
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	135.93	107.95
Skin Temperature (°F)	122.07	121.57
Velocity ***	5,782.55	0.72
Reynold's Number	2,128	4,662
Prandtl Number	0.7262	4.1372
Bulk Visc (lbm/ft·hr)	0.0485	1.5151
Skin Visc (lbm/ft·hr)		1.3267
Density (lbm/ft³)	0.0631	61.8887
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0160	0.3658

Tube-Side hi (BTU/hr·ft²·°F)	242.87
j Factor	0.0105
Air-Side ho (BTU/hr·ft²·°F)	18.04
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.00200000
U Overall (BTU/hr·ft²·°F)	7.96
Effective Area (ft²)	717.51
LMTD	27.13
Total Heat Transferred (BTU/hr)	154,912
Surface Effectiveness (Eta)	0.8907
Sensible Heat Transferred (BTU/hr)	154,912
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	111,037.50	19,492.05
Inlet Temperature (°F)	133.14	100.00
Outlet Temperature (°F)	128.40	113.54
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	130.77	106.77
Skin Temperature (°F)	118.96	118.53
Velocity ***	5,782.55	0.72
Reynold's Number	2,142	4,606
Prandtl Number	0.7266	4.1926
Bulk Visc (lbm/ft·hr)	0.0482	1.5335
Skin Visc (lbm/ft·hr)		1.3653
Density (lbm/ft^3)	0.0636	61.9050
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3654

Tube-Side hi (BTU/hr·ft^2·°F)	239.09
j Factor	0.0105
Air-Side ho (BTU/hr·ft^2·°F)	17.99
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.00200000
U Overall (BTU/hr·ft^2·°F)	7.89
Effective Area (ft^2)	717.51
LMTD	23.29
Total Heat Transferred (BTU/hr)	131,790
Surface Effectiveness (Eta)	0.8909
Sensible Heat Transferred (BTU/hr)	131,790
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Moist Air Properties -- Given Dry Bulb and Specific Humidity

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	128.4	°F	
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.063627362	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001289958	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.064917319	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	2.131789935	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	21.19695334	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

18:48:38 **PROTO-HX 3.01 by Proto-Power Corporation (SN#PHX-0000)** 07/10/98

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Data Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils-

Fouling Sensitivity (Tube f = 0.0000)

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	32,483.00 acfm	82.00 gpm
Inlet Dry Bulb Temp	°F	105.00 °F
Inlet Wet Bulb Temp	°F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
Fouling Sensitivity (Tube f = 0.0000)

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date
Air Flow (acfm)
Air Dry Bulb Temp In (°F)
Air Dry Bulb Temp Out (°F)
Relative Humidity In (%)
Relative Humidity Out (%)
Wet Bulb Temp In (°F)
Wet Bulb Temp Out (°F)
Atmospheric Pressure
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)
Condensate Temperature (°F)

Extrapolation Data

Tube Flow (gpm)	27.30
Air Flow (acfm)	29,078.95
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	128.4
Inlet Relative Humidity (%)	21.20
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

← Adjusted to match front coil mass flow

Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
Fouling Sensitivity (Tube f = 0.0000)

Extrapolation Calculation Summary

	Air-Side	**Tube-Side**		
Mass Flow (lbm/hr)	111,037.47	13,574.82	Tube-Side hi (BTU/hr·ft^2·°F)	
Inlet Temperature (°F)	128.40	100.00	j Factor	
Outlet Temperature (°F)	116.70	124.00	Air-Side ho (BTU/hr·ft^2·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity			Overall Fouling (hr·ft^2·°F/BTU)	0.00200000
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft^2·°F)	
Velocity ***			Effective Area (ft^2)	5,740.10
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	324,952
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft^3)			Sensible Heat Transferred (BTU/hr)	324,952
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	**Tube-Side**		
Mass Flow (lbm/hr)	111,037.47	13,574.82	Tube-Side hi (BTU/hr·ft^2·°F)	168.13
Inlet Temperature (°F)	128.40	121.01	j Factor	0.0115
Outlet Temperature (°F)	127.53	124.56	Air-Side ho (BTU/hr·ft^2·°F)	19.83
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.00200000
Average Temp (°F)	127.97	122.79		
Skin Temperature (°F)	125.96	125.88	U Overall (BTU/hr·ft^2·°F)	6.76
Velocity ***	5,782.55	0.50	Effective Area (ft^2)	717.51
Reynold's Number	1,612	3,750	LMTD	4.96
Prandtl Number	0.7268	3.5322	Total Heat Transferred (BTU/hr)	24,066
Bulk Visc (lbm/ft·hr)	0.0480	1.3118		
Skin Visc (lbm/ft·hr)		1.2751	Surface Effectiveness (Eta)	0.8815
Density (lbm/ft^3)	0.0637	61.6679	Sensible Heat Transferred (BTU/hr)	24,066
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0159	0.3710	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

Fouling Sensitivity (Tube f = 0.0000)

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	111,037.47	13,574.82	Tube-Side hi (BTU/hr·ft^2·°F)	165.77
Inlet Temperature (°F)	127.53	119.68	j Factor	0.0115
Outlet Temperature (°F)	126.62	123.43	Air-Side ho (BTU/hr·ft^2·°F)	19.82
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.00200000
Average Temp (°F)	127.08	121.56		
Skin Temperature (°F)	124.96	124.87	U Overall (BTU/hr·ft^2·°F)	6.71
Velocity ***	5,782.55	0.50	Effective Area (ft^2)	717.51
Reynold's Number	1,614	3,708	LMTD	5.29
Prandtl Number	0.7269	3.5768	Total Heat Transferred (BTU/hr)	25,442
Bulk Visc (lbm/ft·hr)	0.0479	1.3269		
Skin Visc (lbm/ft·hr)		1.2869	Surface Effectiveness (Eta)	0.8815
Density (lbm/ft^3)	0.0638	61.6874	Sensible Heat Transferred (BTU/hr)	25,442
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0158	0.3705	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	111,037.47	13,574.82	Tube-Side hi (BTU/hr·ft^2·°F)	160.04
Inlet Temperature (°F)	126.62	116.02	j Factor	0.0115
Outlet Temperature (°F)	125.40	121.01	Air-Side ho (BTU/hr·ft^2·°F)	19.81
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.00200000
Average Temp (°F)	126.01	118.51		
Skin Temperature (°F)	123.19	123.08	U Overall (BTU/hr·ft^2·°F)	6.56
Velocity ***	5,782.55	0.50	Effective Area (ft^2)	717.51
Reynold's Number	1,617	3,603	LMTD	7.19
Prandtl Number	0.7270	3.6909	Total Heat Transferred (BTU/hr)	33,875
Bulk Visc (lbm/ft·hr)	0.0479	1.3655		
Skin Visc (lbm/ft·hr)		1.3083	Surface Effectiveness (Eta)	0.8816
Density (lbm/ft^3)	0.0640	61.7345	Sensible Heat Transferred (BTU/hr)	33,875
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0158	0.3695	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2). Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	111,037.47	13,574.82	Tube-Side hi (BTU/hr·ft^2·°F)	157.40
Inlet Temperature (°F)	125.40	114.65	j Factor	0.0115
Outlet Temperature (°F)	124.17	119.68	Air-Side ho (BTU/hr·ft^2·°F)	19.80
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.00200000
Average Temp (°F)	124.78	117.17		
Skin Temperature (°F)	121.95	121.84	U Overall (BTU/hr·ft^2·°F)	6.50
Velocity ***	5,782.55	0.50	Effective Area (ft^2)	717.51
Reynold's Number	1,619	3,557	LMTD	7.32
Prandtl Number	0.7271	3.7434	Total Heat Transferred (BTU/hr)	34,118
Bulk Visc (lbm/ft·hr)	0.0478	1.3832		
Skin Visc (lbm/ft·hr)		1.3235	Surface Effectiveness (Eta)	0.8816
Density (lbm/ft^3)	0.0641	61.7551	Sensible Heat Transferred (BTU/hr)	34,118
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0158	0.3691	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	111,037.47	13,574.82	Tube-Side hi (BTU/hr·ft^2·°F)	148.72
Inlet Temperature (°F)	124.17	109.14	j Factor	0.0115
Outlet Temperature (°F)	122.49	116.02	Air-Side ho (BTU/hr·ft^2·°F)	19.78
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.00200000
Average Temp (°F)	123.33	112.58		
Skin Temperature (°F)	119.47	119.31	U Overall (BTU/hr·ft^2·°F)	6.27
Velocity ***	5,782.55	0.50	Effective Area (ft^2)	717.51
Reynold's Number	1,622	3,401	LMTD	10.36
Prandtl Number	0.7272	3.9314	Total Heat Transferred (BTU/hr)	46,594
Bulk Visc (lbm/ft·hr)	0.0477	1.4464		
Skin Visc (lbm/ft·hr)		1.3552	Surface Effectiveness (Eta)	0.8817
Density (lbm/ft^3)	0.0643	61.8230	Sensible Heat Transferred (BTU/hr)	46,594
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0158	0.3675	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Fouling Sensitivity (Tube f = 0.0000)

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	111,037.47	13,574.82	Tube-Side hi (BTU/hr·ft^2·°F)	146.29
Inlet Temperature (°F)	122.49	108.12	j Factor	0.0115
Outlet Temperature (°F)	120.90	114.65	Air-Side ho (BTU/hr·ft^2·°F)	19.76
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.00200000
Average Temp (°F)	121.70	111.38		
Skin Temperature (°F)	118.03	117.88	U Overall (BTU/hr·ft^2·°F)	6.20
Velocity ***	5,782.55	0.50	Effective Area (ft^2)	717.51
Reynold's Number	1,626	3,361	LMTD	9.94
Prandtl Number	0.7273	3.9829	Total Heat Transferred (BTU/hr)	44,247
Bulk Visc (lbm/ft·hr)	0.0476	1.4636		
Skin Visc (lbm/ft·hr)		1.3738	Surface Effectiveness (Eta)	0.8818
Density (lbm/ft^3)	0.0645	61.8403	Sensible Heat Transferred (BTU/hr)	44,247
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0157	0.3670	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	111,037.47	13,574.82	Tube-Side hi (BTU/hr·ft^2·°F)	133.31
Inlet Temperature (°F)	120.90	100.05	j Factor	0.0115
Outlet Temperature (°F)	118.68	109.14	Air-Side ho (BTU/hr·ft^2·°F)	19.74
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.00200000
Average Temp (°F)	119.79	104.60		
Skin Temperature (°F)	114.69	114.49	U Overall (BTU/hr·ft^2·°F)	5.84
Velocity ***	5,782.55	0.50	Effective Area (ft^2)	717.51
Reynold's Number	1,630	3,137	LMTD	14.71
Prandtl Number	0.7274	4.2974	Total Heat Transferred (BTU/hr)	61,662
Bulk Visc (lbm/ft·hr)	0.0475	1.5683		
Skin Visc (lbm/ft·hr)		1.4195	Surface Effectiveness (Eta)	0.8819
Density (lbm/ft^3)	0.0647	61.9344	Sensible Heat Transferred (BTU/hr)	61,662
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0157	0.3645	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	111,037.47	13,574.82
Inlet Temperature (°F)	118.68	100.02
Outlet Temperature (°F)	116.70	108.12
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	117.69	104.07
Skin Temperature (°F)	113.14	112.97
Velocity ***	5,782.55	0.50
Reynold's Number	1,635	3,120
Prandtl Number	0.7276	4.3236
Bulk Visc (lbm/ft·hr)	0.0473	1.5770
Skin Visc (lbm/ft·hr)		1.4408
Density (lbm/ft^3)	0.0649	61.9414
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0156	0.3643

Tube-Side hi (BTU/hr·ft^2·°F)	132.06
j Factor	0.0115
Air-Side ho (BTU/hr·ft^2·°F)	19.72
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.00200000
U Overall (BTU/hr·ft^2·°F)	5.81
Effective Area (ft^2)	717.51
LMTD	13.19
Total Heat Transferred (BTU/hr)	54,947
Surface Effectiveness (Eta)	0.8820
Sensible Heat Transferred (BTU/hr)	54,947
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Data Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils
Fouling Sensitivity (Tube f = 0.0040)

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	33,546.00 acfm	118.00 gpm
Inlet Dry Bulb Temp	150.00 °F	105.00 °F
Inlet Wet Bulb Temp	92.00 °F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.004000 ←
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle VY Cooler 04A
	j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	4
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	2.000
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date
Air Flow (acfm)
Air Dry Bulb Temp In (°F)
Air Dry Bulb Temp Out (°F)
Relative Humidity In (%)
Relative Humidity Out (%)
Wet Bulb Temp In (°F)
Wet Bulb Temp Out (°F)
Atmospheric Pressure
Tube Flow (gpm)
Tube Temp In (°F)
Tube Temp Out (°F)
Condensate Temperature (°F)

Extrapolation Data

Tube Flow (gpm)	39.20
Air Flow (acfm)	29,874.00
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	148.0
Inlet Relative Humidity (%)	12.76
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils

Fouling Sensitivity (Tube f = 0.0040)

Extrapolation Calculation Summary

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110,394.51	19,492.05	Tube-Side hi (BTU/hr·ft²·°F)	
Inlet Temperature (°F)	148.00	100.00	j Factor	
Outlet Temperature (°F)	132.06	122.59	Air-Side ho (BTU/hr·ft²·°F)	
Inlet Specific Humidity			Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity			Overall Fouling (hr·ft²·°F/BTU)	0.06143499
Average Temp (°F)				
Skin Temperature (°F)			U Overall (BTU/hr·ft²·°F)	
Velocity ***			Effective Area (ft²)	2,870.05
Reynold's Number			LMTD	
Prandtl Number			Total Heat Transferred (BTU/hr)	440,315
Bulk Visc (lbm/ft·hr)				
Skin Visc (lbm/ft·hr)			Surface Effectiveness (Eta)	
Density (lbm/ft³)			Sensible Heat Transferred (BTU/hr)	440,315
Cp (BTU/lbm·°F)			Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)			Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110,394.51	19,492.05	Tube-Side hi (BTU/hr·ft²·°F)	268.27
Inlet Temperature (°F)	148.00	112.40	j Factor	0.0106
Outlet Temperature (°F)	144.01	123.72	Air-Side ho (BTU/hr·ft²·°F)	18.06
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft²·°F/BTU)	0.06143499
Average Temp (°F)	146.01	118.06		
Skin Temperature (°F)	136.31	126.70	U Overall (BTU/hr·ft²·°F)	5.58
Velocity ***	5,749.07	0.72	Effective Area (ft²)	717.51
Reynold's Number	2,089	5,151	LMTD	27.52
Prandtl Number	0.7253	3.7084	Total Heat Transferred (BTU/hr)	110,158
Bulk Visc (lbm/ft·hr)	0.0491	1.3714		
Skin Visc (lbm/ft·hr)		1.2657	Surface Effectiveness (Eta)	0.8906
Density (lbm/ft³)	0.0620	61.7415	Sensible Heat Transferred (BTU/hr)	110,158
Cp (BTU/lbm·°F)	0.2402	0.9989	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0163	0.3694	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110,394.51	19,492.05	Tube-Side hi (BTU/hr·ft^2·°F)	263.29
Inlet Temperature (°F)	144.01	111.04	j Factor	0.0105
Outlet Temperature (°F)	140.33	121.47	Air-Side ho (BTU/hr·ft^2·°F)	18.02
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.06143499
Average Temp (°F)	142.17	116.25		
Skin Temperature (°F)	133.22	124.36	U Overall (BTU/hr·ft^2·°F)	5.54
Velocity ***	5,749.07	0.72	Effective Area (ft^2)	717.51
Reynold's Number	2,099	5,062	LMTD	25.53
Prandtl Number	0.7257	3.7797	Total Heat Transferred (BTU/hr)	101,543
Bulk Visc (lbm/ft·hr)	0.0489	1.3954		
Skin Visc (lbm/ft·hr)		1.2930	Surface Effectiveness (Eta)	0.8907
Density (lbm/ft^3)	0.0624	61.7689	Sensible Heat Transferred (BTU/hr)	101,543
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0162	0.3688	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110,394.51	19,492.05	Tube-Side hi (BTU/hr·ft^2·°F)	237.18
Inlet Temperature (°F)	140.33	99.97	j Factor	0.0105
Outlet Temperature (°F)	135.95	112.40	Air-Side ho (BTU/hr·ft^2·°F)	17.99
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^2·°F/BTU)	0.06143499
Average Temp (°F)	138.14	106.18		
Skin Temperature (°F)	127.46	116.91	U Overall (BTU/hr·ft^2·°F)	5.36
Velocity ***	5,749.07	0.72	Effective Area (ft^2)	717.51
Reynold's Number	2,109	4,579	LMTD	31.51
Prandtl Number	0.7260	4.2204	Total Heat Transferred (BTU/hr)	121,070
Bulk Visc (lbm/ft·hr)	0.0486	1.5428		
Skin Visc (lbm/ft·hr)		1.3867	Surface Effectiveness (Eta)	0.8909
Density (lbm/ft^3)	0.0628	61.9130	Sensible Heat Transferred (BTU/hr)	121,070
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0161	0.3651	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Calculation Report for: 1(2)VY04A-Front - CSCS Equipment Area Cooling Coils
Fouling Sensitivity (Tube f = 0.0040)

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,394.51	19,492.05
Inlet Temperature (°F)	135.95	99.99
Outlet Temperature (°F)	132.06	111.04
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	134.00	105.51
Skin Temperature (°F)	124.50	115.12
Velocity ***	5,749.07	0.72
Reynold's Number	2,121	4,547
Prandtl Number	0.7264	4.2527
Bulk Visc (lbm/ft·hr)	0.0484	1.5535
Skin Visc (lbm/ft·hr)		1.4108
Density (lbm/ft³)	0.0632	61.9221
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0160	0.3649

Tube-Side hi (BTU/hr·ft²·°F)	235.01
j Factor	0.0105
Air-Side ho (BTU/hr·ft²·°F)	17.95
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.06143499
U Overall (BTU/hr·ft²·°F)	5.34
Effective Area (ft²)	717.51
LMTD	28.09
Total Heat Transferred (BTU/hr)	107,544
Surface Effectiveness (Eta)	0.8911
Sensible Heat Transferred (BTU/hr)	107,544
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Moist Air Properties -- Given Dry Bulb and Specific Humidity

Total Pressure:	P =	14.315	psia	
Dry Bulb Temperature:	T =	132.06	^{o}F	
Specific Humidity:	W =	0.020273629		
Water Vapor Pressure:	Pv = (W*Rv*P)/(Ra+(W*Rv)) =	0.451874518	psia	Equation [11]
Dry Air Pressure:	Pa =P - Pv =	13.86312548	psia	Equation [4]
Dry Air Density:	Rho a = (144/53.352)*(Pa/(459.67+T)) =	0.063233811	lbm/ft^3	Equation [5]
Water Vapor Density:	Rho v = (144/85.778)*(Pv/(459.67+T)) =	0.001281979	lbm/ft^3	Equation [6]
Moist Air Density:	Rho = Rho a + Rho v =	0.064515789	lbm/ft^3	Equation [7]
Saturated Air Pressure:	$Ps = a+(b*T)+(c*T^2)+(d*T^3)+(e*T^4)+(f*T^5) =$	2.350592396	psia	Equation [8]
Moist Air Relative Humidity:	RH = Pv /Ps =	19.22385687	%	Equation [15]
Equation Coefficients:	a =	2.358607E-02		
	b =	1.007276E-03		
	c =	1.888033E-05		
	d =	3.775047E-07		
	e =	4.871208E-10		
	f =	2.109071E-11		

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Data Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
Fouling Sensitivity (Tube f = 0.0040)

Air Coil Heat Exchanger Input Parameters

	Air-Side	Tube-Side
Fluid Quantity, Total	32,483.00 acfm	82.00 gpm
Inlet Dry Bulb Temp	°F	105.00 °F
Inlet Wet Bulb Temp	°F	
Inlet Relative Humidity	%	
Outlet Dry Bulb Temperature	°F	°F
Outlet Wet Bulb Temp	°F	
Outlet Relative Humidity	%	

Tube Fluid Name	Fresh Water
Tube Fouling Factor	0.004000 ←
Air-Side Fouling	0.002000
Design Heat Transfer (BTU/hr)	
Atmospheric Pressure	14.315
Sensible Heat Ratio	1.00
Performance Factor (% Reduction)	0.000
Heat Exchanger Type	Counter Flow
Fin Type	Circular Fins
Fin Configuration	LaSalle Cooler 1(2)VY04A j = EXP[-1.9210 + -0.3441 * LOG(Re)]
Coil Finned Length (in)	105.000
Fin Pitch (Fins/Inch)	10.000
Fin Conductivity (BTU/hr·ft·°F)	128.000
Fin Tip Thickness (inches)	0.0120
Fin Root Thickness (inches)	0.0120
Circular Fin Height (inches)	1.347
Number of Coils Per Unit	2
Number of Tube Rows	8
Number of Tubes Per Row	20.00
Active Tubes Per Row	20.00
Tube Inside Diameter (in)	0.5270
Tube Outside Diameter (in)	0.6250
Longitudinal Tube Pitch (in)	1.500
Transverse Tube Pitch (in)	1.370
Number of Serpentines	2.000
Tube Wall Conductivity (BTU/hr·ft·°F)	225.00

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

Fouling Sensitivity (Tube f = 0.0040)

Calculation Specifications

Constant Inlet Temperature Method Was Used
Extrapolation Was to User Specified Conditions
Design Fouling Factors Were Used

Test Data

Data Date	
Air Flow (acfm)	
Air Dry Bulb Temp In (°F)	
Air Dry Bulb Temp Out (°F)	
Relative Humidity In (%)	
Relative Humidity Out (%)	
Wet Bulb Temp In (°F)	
Wet Bulb Temp Out (°F)	
Atmospheric Pressure	
Tube Flow (gpm)	
Tube Temp In (°F)	
Tube Temp Out (°F)	
Condensate Temperature (°F)	

Extrapolation Data

Tube Flow (gpm)	27.30
Air Flow (acfm)	29,090.18
Tube Inlet Temp (°F)	100.00
Air Inlet Temp (°F)	132.1
Inlet Relative Humidity (%)	19.22
Inlet Wet Bulb Temp (°F)	0.00
Atmospheric Pressure	14.315

← Adjusted to match front coil mass flow

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils

Fouling Sensitivity (Tube f = 0.0040)

Extrapolation Calculation Summary

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,394.53	13,574.82
Inlet Temperature (°F)	132.06	100.00
Outlet Temperature (°F)	120.05	124.49
Inlet Specific Humidity		
Outlet Specific Humidity		
Average Temp (°F)		
Skin Temperature (°F)		
Velocity ***		
Reynold's Number		
Prandtl Number		
Bulk Visc (lbm/ft·hr)		
Skin Visc (lbm/ft·hr)		
Density (lbm/ft³)		
Cp (BTU/lbm·°F)		
K (BTU/hr·ft·°F)		

Tube-Side hi (BTU/hr·ft²·°F)	
j Factor	
Air-Side ho (BTU/hr·ft²·°F)	
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.06143499
U Overall (BTU/hr·ft²·°F)	
Effective Area (ft²)	5,740.10
LMTD	
Total Heat Transferred (BTU/hr)	331,663
Surface Effectiveness (Eta)	
Sensible Heat Transferred (BTU/hr)	331,663
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 1(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,394.53	13,574.82
Inlet Temperature (°F)	132.06	120.78
Outlet Temperature (°F)	131.00	125.08
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	131.53	122.93
Skin Temperature (°F)	129.15	126.59
Velocity ***	5,749.07	0.50
Reynold's Number	1,596	3,755
Prandtl Number	0.7266	3.5272
Bulk Visc (lbm/ft·hr)	0.0482	1.3101
Skin Visc (lbm/ft·hr)		1.2669
Density (lbm/ft³)	0.0634	61.6657
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0159	0.3710

Tube-Side hi (BTU/hr·ft²·°F)	168.53
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.79
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.06143499
U Overall (BTU/hr·ft²·°F)	4.83
Effective Area (ft²)	717.51
LMTD	8.41
Total Heat Transferred (BTU/hr)	29,136
Surface Effectiveness (Eta)	0.8817
Sensible Heat Transferred (BTU/hr)	29,136
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 2(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,394.53	13,574.82
Inlet Temperature (°F)	131.00	119.55
Outlet Temperature (°F)	129.94	123.90
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	130.47	121.72
Skin Temperature (°F)	128.07	125.48
Velocity ***	5,749.07	0.50
Reynold's Number	1,598	3,713
Prandtl Number	0.7266	3.5707
Bulk Visc (lbm/ft·hr)	0.0481	1.3249
Skin Visc (lbm/ft·hr)		1.2798
Density (lbm/ft³)	0.0635	61.6847
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3706

Tube-Side hi (BTU/hr·ft²·°F)	166.19
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.78
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.06143499
U Overall (BTU/hr·ft²·°F)	4.80
Effective Area (ft²)	717.51
LMTD	8.56
Total Heat Transferred (BTU/hr)	29,453
Surface Effectiveness (Eta)	0.8817
Sensible Heat Transferred (BTU/hr)	29,453
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 3(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,394.53	13,574.82
Inlet Temperature (°F)	129.94	115.31
Outlet Temperature (°F)	128.59	120.78
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	129.27	118.04
Skin Temperature (°F)	126.24	122.98
Velocity ***	5,749.07	0.50
Reynold's Number	1,600	3,587
Prandtl Number	0.7267	3.7091
Bulk Visc (lbm/ft·hr)	0.0481	1.3716
Skin Visc (lbm/ft·hr)		1.3095
Density (lbm/ft³)	0.0636	61.7417
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3694

Tube-Side hi (BTU/hr·ft²·°F)	159.19
j Factor	0.0116
Air-Side ho (BTU/hr·ft²·°F)	19.77
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.06143499
U Overall (BTU/hr·ft²·°F)	4.71
Effective Area (ft²)	717.51
LMTD	10.99
Total Heat Transferred (BTU/hr)	37,111
Surface Effectiveness (Eta)	0.8818
Sensible Heat Transferred (BTU/hr)	37,111
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

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Calculation Report for: 1(2)VY04A-Back - CSCS Equipment Area Cooling Coils
Fouling Sensitivity (Tube f = 0.0040)

Extrapolation Calculation for Row 4(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,394.53	13,574.82
Inlet Temperature (°F)	128.59	114.19
Outlet Temperature (°F)	127.28	119.55
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	127.94	116.87
Skin Temperature (°F)	124.97	121.77
Velocity ***	5,749.07	0.50
Reynold's Number	1,603	3,547
Prandtl Number	0.7268	3.7550
Bulk Visc (lbm/ft·hr)	0.0480	1.3871
Skin Visc (lbm/ft·hr)		1.3243
Density (lbm/ft^3)	0.0638	61.7595
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0159	0.3690

Tube-Side hi (BTU/hr·ft^2·°F)	156.87
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.75
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.06143499
U Overall (BTU/hr·ft^2·°F)	4.68
Effective Area (ft^2)	717.51
LMTD	10.84
Total Heat Transferred (BTU/hr)	36,360
Surface Effectiveness (Eta)	0.8819
Sensible Heat Transferred (BTU/hr)	36,360
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 5(Dry)

	Air-Side	Tube-Side
Mass Flow (lbm/hr)	110,394.53	13,574.82
Inlet Temperature (°F)	127.28	108.44
Outlet Temperature (°F)	125.59	115.31
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	126.43	111.87
Skin Temperature (°F)	122.63	118.55
Velocity ***	5,749.07	0.50
Reynold's Number	1,606	3,378
Prandtl Number	0.7270	3.9617
Bulk Visc (lbm/ft·hr)	0.0479	1.4565
Skin Visc (lbm/ft·hr)		1.3650
Density (lbm/ft^3)	0.0639	61.8333
Cp (BTU/lbm·°F)	0.2402	0.9988
K (BTU/hr·ft·°F)	0.0158	0.3672

Tube-Side hi (BTU/hr·ft^2·°F)	147.30
j Factor	0.0116
Air-Side ho (BTU/hr·ft^2·°F)	19.74
Tube Wall Resistance (hr·ft^2·°F/BTU	0.00024732
Overall Fouling (hr·ft^2·°F/BTU)	0.06143499
U Overall (BTU/hr·ft^2·°F)	4.55
Effective Area (ft^2)	717.51
LMTD	14.27
Total Heat Transferred (BTU/hr)	46,554
Surface Effectiveness (Eta)	0.8819
Sensible Heat Transferred (BTU/hr)	46,554
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^2), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 6(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110,394.53	13,574.82	Tube-Side hi (BTU/hr·ft^{2}·°F)	145.39
Inlet Temperature (°F)	125.59	107.69	j Factor	0.0115
Outlet Temperature (°F)	124.00	114.19	Air-Side ho (BTU/hr·ft^{2}·°F)	19.72
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^{2}·°F/BTU)	0.06143499
Average Temp (°F)	124.79	110.94		
Skin Temperature (°F)	121.20	117.34	U Overall (BTU/hr·ft^{2}·°F)	4.52
Velocity ***	5,749.07	0.50	Effective Area (ft^{2})	717.51
Reynold's Number	1,610	3,346	LMTD	13.58
Prandtl Number	0.7271	4.0022	Total Heat Transferred (BTU/hr)	44,025
Bulk Visc (lbm/ft·hr)	0.0478	1.4701		
Skin Visc (lbm/ft·hr)		1.3809	Surface Effectiveness (Eta)	0.8820
Density (lbm/ft^{3})	0.0641	61.8466	Sensible Heat Transferred (BTU/hr)	44,025
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0158	0.3669	Heat to Condensate (BTU/hr)	

Extrapolation Calculation for Row 7(Dry)

	Air-Side	Tube-Side		
Mass Flow (lbm/hr)	110,394.53	13,574.82	Tube-Side hi (BTU/hr·ft^{2}·°F)	132.43
Inlet Temperature (°F)	124.00	100.03	j Factor	0.0115
Outlet Temperature (°F)	121.93	108.44	Air-Side ho (BTU/hr·ft^{2}·°F)	19.70
Inlet Specific Humidity	0.0203		Tube Wall Resistance (hr·ft^{2}·°F/BTU	0.00024732
Outlet Specific Humidity	0.0203		Overall Fouling (hr·ft^{2}·°F/BTU)	0.06143499
Average Temp (°F)	122.97	104.23		
Skin Temperature (°F)	118.31	113.32	U Overall (BTU/hr·ft^{2}·°F)	4.32
Velocity ***	5,749.07	0.50	Effective Area (ft^{2})	717.51
Reynold's Number	1,614	3,125	LMTD	18.40
Prandtl Number	0.7272	4.3154	Total Heat Transferred (BTU/hr)	57,038
Bulk Visc (lbm/ft·hr)	0.0477	1.5743		
Skin Visc (lbm/ft·hr)		1.4359	Surface Effectiveness (Eta)	0.8821
Density (lbm/ft^{3})	0.0644	61.9393	Sensible Heat Transferred (BTU/hr)	57,038
Cp (BTU/lbm·°F)	0.2402	0.9988	Latent Heat Transferred (BTU/hr)	
K (BTU/hr·ft·°F)	0.0157	0.3644	Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft^{2}), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Extrapolation Calculation for Row 8(Dry)

	Air-Side	**Tube-Side**
Mass Flow (lbm/hr)	110,394.53	13,574.82
Inlet Temperature (°F)	121.93	100.03
Outlet Temperature (°F)	120.05	107.69
Inlet Specific Humidity	0.0203	
Outlet Specific Humidity	0.0203	
Average Temp (°F)	120.99	103.86
Skin Temperature (°F)	116.74	112.19
Velocity ***	5,749.07	0.50
Reynold's Number	1,618	3,113
Prandtl Number	0.7273	4.3339
Bulk Visc (lbm/ft·hr)	0.0475	1.5804
Skin Visc (lbm/ft·hr)		1.4519
Density (lbm/ft³)	0.0646	61.9442
Cp (BTU/lbm·°F)	0.2402	0.9989
K (BTU/hr·ft·°F)	0.0157	0.3643

Tube-Side hi (BTU/hr·ft²·°F)	131.54
j Factor	0.0115
Air-Side ho (BTU/hr·ft²·°F)	19.68
Tube Wall Resistance (hr·ft²·°F/BTU	0.00024732
Overall Fouling (hr·ft²·°F/BTU)	0.06143499
U Overall (BTU/hr·ft²·°F)	4.31
Effective Area (ft²)	717.51
LMTD	16.83
Total Heat Transferred (BTU/hr)	51,985
Surface Effectiveness (Eta)	0.8822
Sensible Heat Transferred (BTU/hr)	51,985
Latent Heat Transferred (BTU/hr)	
Heat to Condensate (BTU/hr)	

*** Air Mass Velocity (Lbm/hr·ft²), Tube Fluid Velocity (ft/sec); Air Density at Inlet T, Other Properties at Average T

Attachment N to
Proto-Power Calculation
97-198
Revision A

Proto-HX Model Database

Two separate models are saved on the attached disks as follows:

FRONT COIL- (2 Disks)

Name:	vy-04a-f.phx
Size:	1,409,024 bytes
Date:	7/10/98
Time:	4:09:12 pm

BACK COIL -(2 Disks)

Name:	vy-04a-b.phx
Size:	1,409,024 bytes
Date:	7/10/98
Time:	4:09:30 pm