Design Project #1

Thermal Fluids Design – MAE 3524

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Section 1

This paper will explore the process of selecting and validating a compressor to replace an existing compressor in a vapor compression cycle. The purpose of replacing the compressor is to reduce power consumption while cooling the specified space more efficiently.

This paper references software, Engineering Equation Solver (EES), which is used to find thermodynamic properties and solve systems of equations presented by the problem.

In this paper the size that needs to be cooled is 830 ft^2 and the original vapor compression cycle is defined in Table 1.1.

Using the given information it is possible to use common assumptions and the first law of thermodynamics to fully define the system. The EES code below in Fig 1 is used to evaluate the original system. After the needed thermodynamic properties are found it is possible to find the systems isentropic efficiency, coefficient of performance (COP), energy cost per hour, energy cost per month, and capacity. Table 1.1. also displays the size of the space that the system is being optimized for and the capacity required to cool that space.

Overall isentropic efficiency	0.6722 or 67.22%
COP	4.11
Energy cost ($/hour)	0.2576
Energy cost ($/month)	61.82
Capacity of the existing AC system (W)	9876
Your house size (ft^2)	830
Capacity required for your house (W)	6081

Table 1 - Evaluation of Original System

```
{Given for Current System}
mdot_ref=62.99[g/s]
P=2403[W] {Power at typical operating conditions}
P_2=2420[kPa] {high-side operating temp}
T_4=5[C] {Evaporator temperature}

{Assumtions}
x_1=1
T_1=T_4
s_2s=s_1
P_3=P_2
P_2s=P_2
h_4=h_3
x_3=0 {Subcooled not saturated}

{Design Variables}
electricityPrice=0.1072[$/kWh]
opperatingHours=240[hr]
houseSize=830[ft^2]

{Solving}
h_1=enthalpy(R410A,T=T_1,x=x_1)
P=mdot_ref*(h_2-h_1)
s_1=entropy(R410A,T=T_1,x=x_1)
h_2s=enthalpy(R410A,s=s_2s,P=P_2s)
efficiency_isentropic=(h_2s-h_1)/(h_2-h_1)*100

h_3=enthalpy(R410A,P=P_3,x=x_3)
COP=(h_1-h_4)/(h_2-h_1)

cost_hour=P*convert(W,kW)*electricityPrice
cost_month=cost_hour*opperatingHours

capacity=mdot_ref*(h_1-h_4)*convert(kJ,J)/convert(kg,g)
capacity_required=houseSize*25*convert(Btu/hr,W)
```

Table 2 - Section 1 Calculations

SOLUTION

Unit Settings: SI C kPa kJ mass deg

$capacity$ = 9876 [W]	$capacity_{required}$ = 6081 [W]
COP = 4.11	$cost_{hour}$ = 0.2576 [$/hr]
$cost_{month}$ = 61.82 [$/month]	$efficiency_{isentropic}$ = 67.22 [%]
electricityPrice = 0.1072 [$/kWh]	houseSize = 830 [ft^2]
h_1 = 422.8 [kJ/kg]	h_2 = 461 [kJ/kg]
h_{2s} = 448.5 [kJ/kg]	h_3 = 266 [kJ/kg]
h_4 = 266 [kJ/kg]	$mdot_{ref}$ = 62.99 [g/s]
opperatingHours = 240 [hr]	P = 2403 [W]
P_2 = 2420 [kPa]	P_{2s} = 2420 [kPa]
P_3 = 2420 [kPa]	s_1 = 1.801 [kJ/kg-K]
s_{2s} = 1.801 [kJ/kg-K]	T_1 = 5 [C]
T_4 = 5 [C]	x_1 = 1
x_3 = 0	

Table 3 - Section 1 Results

Section 2

This project chose to focus the scope on Copeland compressors. It was possible to find two suitable compressors that met all the design requirements. The two selections fit within the physical bounds, use R410A refrigerant, and use single phase 60Hz 208/230 V power input. The compressors that have been selected are the CP22K8ME-PFV and the ZP21K6E-PFV. More information about each compressor can be seen from Table 4.

As stated previously, the goal of this paper is to explore possible replacements for a compressor to decrease the economic cost and increase efficiency of the current system.

	1st alternative	2nd alternative	Units
Manufacturer	Copeland	Copeland	
Model number	ZP21kE-PFV	CP22K8ME	
Refrigerant	R410A	R410A	
Motor frequency	60	60	Hz
Motor phase (1 or 3)	1	1	
Motor voltage	208-230	208-230	V
Performance @7°C/54°C rating conditions			
Capacity	6213	6213	W
Power	2100	2100	W
EER	17.24	17.18	Btu/h-W
Other specifications			
Overall length	9.56	9.30	In
Overall width	9.56	9.09	in
Overall height	14.94	14.12	In
RPM	3500	3500	RPM

Table 4 - Alternative Compressors

Section 3

To aid the evaluation of the compressors mathematical model were created in EES using the compressor coefficients provided by the Copeland. These coefficients can be seen on Table 5 and Table XXX. The models were validated against the manufacture data so that they could be used to predict how to compressor will function under the operating conditions.

Compressor 1

Copeland Compressor Model CP22K8ME-PFV:			
Coefficient #	Capacity Coefficients (W)	Power Coefficients (W)	Mass Flowrate Coefficient (g/s)
0	-3957.961381	2318.802413	104.5511514
1	1213.724604	-34.26340731	13.07182007
2	256.6592867	-25.18508254	-2.001541182
3	5.913531234	-0.4511599559	0.03815445222
4	-13.25473112	0.8331550691	-0.15083255
5	-1.168179404	0.1648776491	0.04198394854
6	0.01720849503	-0.003695735428	0.000200298596
7	-0.03324154833	0.006614888271	-0.000111599993
8	0.04853011721	-0.004215340349	0.0006744688395
9	-0.00329759596	-0.0001600304257	-0.0002345065605

Table 5 - CP22K8ME-PFV Coefficients

	At 7°C/54°C			At 7°C/38°C		
CP22K8ME-PFV	Manufacturer's value	Calculated Value	% Error	Manufacturer's value	Calculated Value	% Error
Capacity (W)	6213	6219	0.1031%	8909	8776	1.489%
Power (W)	2100	2081	0.8957	1690	1693	0.207%
Mass flowrate (g/s)	40.82	40.57	0.6106%	47.38	46.83	1.162%

Table 6 - CP22K8ME-PFV Validation Data

```
{Section 3b - CP22K8ME-PFV}

T_evap1=converttemp(C,F,7)
T_cond1=converttemp(C,F,54)

capacity1=(C[0]+(C[1]*T_evap1)+(C[2]*T_cond1)+(C[3]*T_evap1^2)+(C[4]*T_evap1*T_cond1)+(C[5]*T_cond1^2)+(C[6]*T_evap1^3)+(C[7]*T_cond1*T_evap1^2)+(C[8]*T_evap1*T_cond1^2)+(C[9]*T_cond1^3))*convert(Btu/hr,w)

power1=W[0]+(W[1]*T_evap1)+(W[2]*T_cond1)+(W[3]*T_evap1^2)+(W[4]*T_evap1*T_cond1)+(W[5]*T_cond1^2)+(W[6]*T_evap1^3)+(W[7]*T_cond1*T_evap1^2)+(W[8]*T_evap1*T_cond1^2)+(W[9]*T_cond1^3)

mdot1=(M[0]+(M[1]*T_evap1)+(M[2]*T_cond1)+(M[3]*T_evap1^2)+(M[4]*T_evap1*T_cond1)+(M[5]*T_cond1^2)+(M[6]*T_evap1^3)+(M[7]*T_cond1*T_evap1^2)+(M[8]*T_evap1*T_cond1^2)+(M[9]*T_cond1^3))*convert(lb_m/hr,g/s)

capacityError1=abs(6213-capacity1)/6213*100
powerError1=abs(2100-power1)/2100*100
mdotError1=abs(40.82-mdot1)/40.82*100

T_evap2=converttemp(C,F,7)
T_cond2=converttemp(C,F,38)

capacity2=(C[0]+(C[1]*T_evap2)+(C[2]*T_cond2)+(C[3]*T_evap2^2)+(C[4]*T_evap2*T_cond2)+(C[5]*T_cond2^2)+(C[6]*T_evap2^3)+(C[7]*T_cond2*T_evap2^2)+(C[8]*T_evap2*T_cond2^2)+(C[9]*T_cond2^3))*convert(Btu/hr,w)

power2=W[0]+(W[1]*T_evap2)+(W[2]*T_cond2)+(W[3]*T_evap2^2)+(W[4]*T_evap2*T_cond2)+(W[5]*T_cond2^2)+(W[6]*T_evap2^3)+(W[7]*T_cond2*T_evap2^2)+(W[8]*T_evap2*T_cond2^2)+(W[9]*T_cond2^3)

mdot2=(M[0]+(M[1]*T_evap2)+(M[2]*T_cond2)+(M[3]*T_evap2^2)+(M[4]*T_evap2*T_cond2)+(M[5]*T_cond2^2)+(M[6]*T_evap2^3)+(M[7]*T_cond2*T_evap2^2)+(M[8]*T_evap2*T_cond2^2)+(M[9]*T_cond2^3))*convert(lb_m/hr,g/s)

capacityError2=abs(8909-capacity2)/8909*100
powerError2=abs(1690-power2)/1690*100
mdotError2=abs(47.38-mdot2)/47.38*100
```

Table 7 - CP22K8ME-PFV Code

capacity1 = 6219 [W]	capacity2 = 8776 [W]	capacityError1 = 0.1031 [%]
capacityError2 = 1.489 [%]	mdot1 = 40.57 [g/s]	mdot2 = 46.83 [g/s]
mdotError1 = 0.6106 [%]	mdotError2 = 1.162 [%]	power1 = 2081 [W]
power2 = 1693 [W]	powerError1 = 0.8957 [%]	powerError2 = 0.207 [%]
T_{cond1} = 129.2 [F]	T_{cond2} = 100.4 [F]	T_{evap1} = 44.6 [F]
T_{evap2} = 44.6 [F]		

Table 8 - CP22K8ME-PFV Solutions

CP22K8ME-PFV	Pressure (kPa)	Temperature (°C)
Evaporator operating conditions	933.2	5
Condenser operating conditions	2420	39.9
Performance parameters at operating conditions		
Actual capacity (W)	1789	
COP	1.173	
Power (W)	1525	
Mass flowrate (g/s)	11.16	
Overall isentropic efficiency (%)	.2088 or 20.88%	
Energy cost ($/month)	$39.23	

Table 9 - CP22K8ME-PFV at Predicted Operation Conditions

Section 2

Copeland Compressor Model ZP21kE-PFV:			
Coefficient #	Capacity Coefficients (W)	Power Coefficients (W)	Mass Flowrate Coefficient (g/s)
0	9293.460431	-11.64166785	165.7200568
1	206.9141431	-14.20991885	2.653310094
2	163.3466375	24.22068232	-0.8551055247
3	3.672799287	-0.1159905293	0.03212726118
4	1.957443702	0.3229410557	0.002873563208
5	-2.358658254	-0.2410616324	0.008444636298
6	0.008241227732	-0.0001343056965	7.57E-05
7	-0.01308792094	0.001119644695	-6.65E-05
8	-0.01510579503	-0.002063122392	1.41E-05
9	0.007534949734	0.001503874012	-4.06E-05

Table 10 - ZP21KE-PFV Coefficients

	At 7°C/54°C			At 7°C/38°C		
ZP21K6E-PFV	Manufacturer's value	Calculated Value	% Error	Manufacturer's value	Calculated Value	% Error
Capacity (W)	6213	6216	0.05425%	8528	8508	0.2388%
Power (W)	2100	2073	0.4624%	1350	1357	0.5387%
Mass flowrate (g/s)	38.93	38.75	1.268%	44.23	44.25	0.04285%

Table 11 - ZP21KE-PFV Validation Data

```
{Section 3b - ZP21K6E-PFV}

T_evap1=converttemp(C,F,7)
T_cond1=converttemp(C,F,54)

capacity1=(C[0]+(C[1]*T_evap1)+(C[2]*T_cond1)+(C[3]*T_evap1^2)+(C[4]*T_evap1*T_cond1)+(C[5]*T_cond1^2)+(C[6]*T_evap1^3)+(C[7]*T_cond1*T_evap1^2)+(C[8]*T_evap1*T_cond1^2)+(C[9]*T_cond1^3))*convert(Btu/hr,W)

power1=W[0]+(W[1]*T_evap1)+(W[2]*T_cond1)+(W[3]*T_evap1^2)+(W[4]*T_evap1*T_cond1)+(W[5]*T_cond1^2)+(W[6]*T_evap1^3)+(W[7]*T_cond1*T_evap1^2)+(W[8]*T_evap1*T_cond1^2)+(W[9]*T_cond1^3)

mdot1=(M[0]+(M[1]*T_evap1)+(M[2]*T_cond1)+(M[3]*T_evap1^2)+(M[4]*T_evap1*T_cond1)+(M[5]*T_cond1^2)+(M[6]*T_evap1^3)+(M[7]*T_cond1*T_evap1^2)+(M[8]*T_evap1*T_cond1^2)+(M[9]*T_cond1^3))*convert(lb_m/hr,g/s)

capacityError1=abs(6213-capacity1)/6213*100
powerError1=abs(2100-power1)/2100*100
mdotError1=abs(38.93-mdot1)/38.93*100

T_evap2=converttemp(C,F,10)
T_cond2=converttemp(C,F,38)

capacity2=(C[0]+(C[1]*T_evap2)+(C[2]*T_cond2)+(C[3]*T_evap2^2)+(C[4]*T_evap2*T_cond2)+(C[5]*T_cond2^2)+(C[6]*T_evap2^3)+(C[7]*T_cond2*T_evap2^2)+(C[8]*T_evap2*T_cond2^2)+(C[9]*T_cond2^3))*convert(Btu/hr,W)

power2=W[0]+(W[1]*T_evap2)+(W[2]*T_cond2)+(W[3]*T_evap2^2)+(W[4]*T_evap2*T_cond2)+(W[5]*T_cond2^2)+(W[6]*T_evap2^3)+(W[7]*T_cond2*T_evap2^2)+(W[8]*T_evap2*T_cond2^2)+(W[9]*T_cond2^3)

mdot2=(M[0]+(M[1]*T_evap2)+(M[2]*T_cond2)+(M[3]*T_evap2^2)+(M[4]*T_evap2*T_cond2)+(M[5]*T_cond2^2)+(M[6]*T_evap2^3)+(M[7]*T_cond2*T_evap2^2)+(M[8]*T_evap2*T_cond2^2)+(M[9]*T_cond2^3))*convert(lb_m/hr,g/s)

capacityError2=abs(8528-capacity2)/8528*100
powerError2=abs(1350-power2)/1350*100
mdotError2=abs(44.23-mdot2)/44.23*100
```

Table 12 - ZP21KE-PFV Code

capacity1 = 6216 [W]	capacity2 = 8508 [W]
capacityError1 = 0.05425 [%]	capacityError2 = 0.2388 [%]
mdot1 = 38.75 [g/s]	mdot2 = 44.25 [g/s]
mdotError1 = 0.4552 [%]	mdotError2 = 0.04285 [%]
power1 = 2073 [W]	power2 = 1357 [W]
powerError1 = 1.268 [%]	powerError2 = 0.5387 [%]
T_{cond1} = 129.2 [F]	T_{cond2} = 100.4 [F]
T_{evap1} = 44.6 [F]	T_{evap2} = 50 [F]

Table 13 - ZP21KE-PFV Solutions

ZP21K6E-PFV	Pressure (kPa)	Temperature (°C)
Evaporator operating conditions	933.2	5
Condenser operating conditions	2420	39.9
Performance parameters at operating conditions		
Actual capacity (W)	3060	
COP	4.952	
Power (W)	617.8	
Mass flowrate (g/s)	14.85	
Overall isentropic efficiency (%)	.6857 or 68.57%	
Energy cost ($/month)	$15.9	

Table 14 - ZP21KE-PFV at Predicted Operation Conditions

Section 4

The compressor that was chosen for the improved design is the ZP21K6E-PFV. This compressor was chosen for its improved efficiency and lower operating cost. This compressor will adequately cool the space while using much less power to do so compared to the other option. Below is the summary of the compressor working at the predicted operation condition and a TS and PH diagram of the VCC.

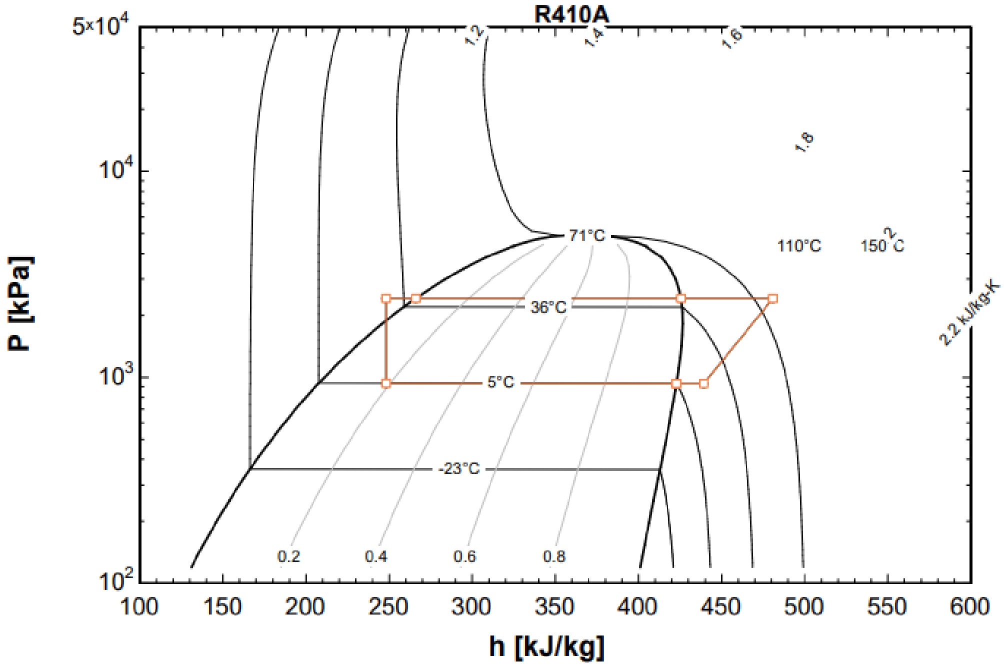

Table 15 - VCC P-h Diagram

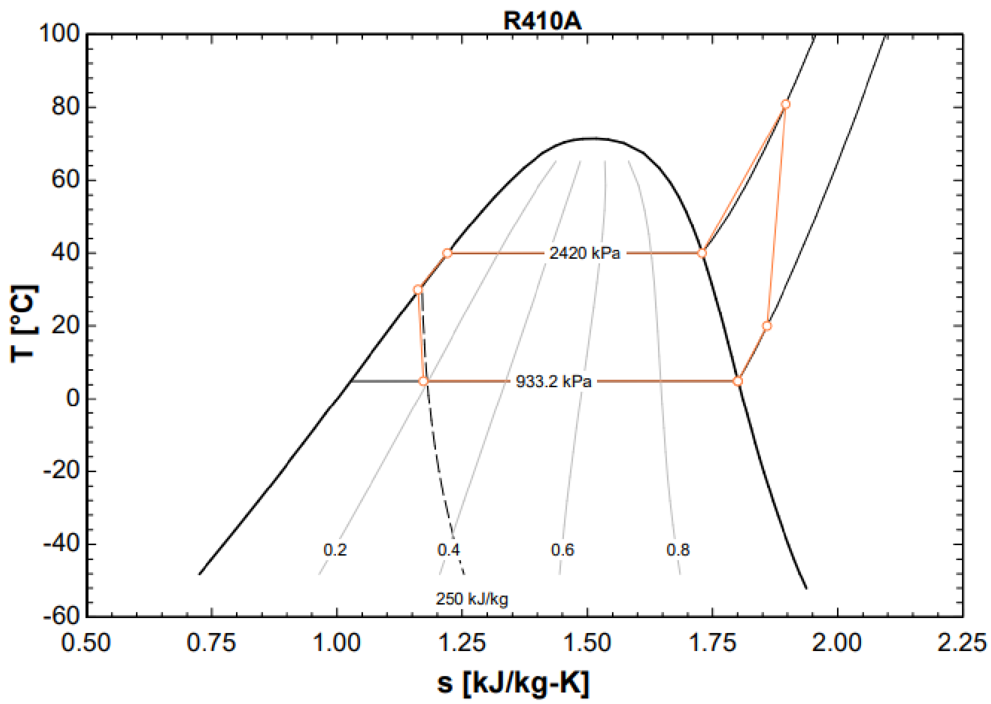

Table 16 - VCC T-s Diagram

Manufacturer	Copeland	
Model number	ZP21K6E-PFV	
Refrigerant	R410A	
Motor frequency	60	Hz
Motor phases (1 or 3)	1	
Motor voltage	208-230	V
Overall length, width & height	9.56 x 9.56 x 14.94	In
Performance @typical operating conditions (P_{cond}=2420 kPa and T_{evap}=5°C)		
Capacity	3060	W
Power	617.8	W
Isentropic efficiency	68.57%	%
Mass flowrate	14.85	g/s
COP	4.952	
Expected energy cost	$15.90	$/month

Appendix

ZP21K6E-PFV
HFC, R-410A, 60 Hz, 1 - Phase, 208/230 V
Air Conditioning
Production Status: Available for sale to all U.S. customers. Please check with your local Emerson Climate Technologies Representative for international availability.

Performance

Evaporator Temp. (°F)	45.00	50
Condensing Temp. (°F)	130.00	100
Return Gas Temp. (°F)	65.00	70
Liquid Temp. (°F)	115.00	85
Capacity (BTU/hr)	21200	29100
Power (W):	2100	1350
Current (Amps):	9.2	5.9
EER(BTU/Wh):	10.15	21.55
Mass Flow (lbs/hr):	309	351
Sound Data @ 50 / 115		
Sound Power (dBA):	66 Avg	71 Max
Vibration mils(peak-peak):	2.0 Avg	3.0 Max
Record Date:	2017-04-25	

Mechanical

Displacement (in^3/Rev):	1.24
Displacement (ft^3/Hr):	
Overall Length (in):	9.56
Overall Width (in):	9.56
Overall Height (in):	14.94
Mounting Length (in):	7.50
Mounting Width (in):	7.50
Mounting Height (in):	15.96
Suction Size (in),Type:	3 / 4 Stub
Discharge Size (in),Type:	1 / 2 Stub
Initial Oil Charge (oz):	21
Oil Recharge (oz):	17
Oil Type:	3MA
Net Weight (lbs):	44.4
Internal Free Volume (in^3):	139.1
Horse Power:	

*Overall compressor height on Copeland Brand Product's specified mounting grommets.

Electrical

LRA High* (Amps):	61.6
LRA Low*(Amps):	
LRA Half Winding (Amps):	
MCC (Amps):	17
Max Operating Current (Amps):	13.0
RLA, MCC/1.4(use for contactor selection)(Amps):	12.1
RLA, MCC/1.56(use for breaker & wire size selection)(Amps):	10.9
RPM:	3500
Box IP :	21
UL File No:	SA2337
UL File Date:	2003-12-16

*Low and High refer to the low and high nominal voltage ranges for which the motor is approved.

Capacitors

Type	Part No	Low MFD	High MFD	Volts	User Description
Run Capacitor	014-0064-08	40.0	0.0	370	
Start Capacitor	014-0061-27	88.0	106.0	330	

Coeff#	Capacity (Btu/hr)	Power (W)	Current (Amps)	Mass Flow (lbs/hr)
0	9293.46043129146	-11.6416678525828	0.725821110590602	165.720056779625
1	206.914143086471	-14.2099188537421	-0.043939195129269	2.65331009444507
2	163.346637548538	24.2206823170219	0.0831853874029448	-0.855105524710698
3	3.67279928664645	-0.115990529345884	-0.000387786308462684	0.0321272611835106
4	1.95744370159013	0.322941055681285	0.000986809471155782	0.00287356320829701
5	-2.35865825432531	-0.241061632363828	-0.000809615070936676	0.00844463629811663
6	0.00824122773173085	-0.000134305696511328	1.10873133675929E-08	7.57498308205721E-05
7	-0.0130879209361424	0.00111964469510363	3.09339628769553E-06	-6.64898974569988E-05
8	-0.015105795030411	-0.00206312239195681	-6.52933080454101E-06	1.41195041829625E-05
9	0.00753494973425965	0.00150387401196607	5.67528050189867E-06	-4.06172005097752E-05

CP22K8ME-PFV
HFC, R-410A, 60 Hz, 1 - Phase, 208/230 V
High Temp
Production Status: Available for sale to all U.S. customers. Please check with your local Emerson Climate Technologies Representative for international availability.

Performance		
Evaporator Temp. (°F)	45.00	45
Condensing Temp. (°F)	130.00	100
Return Gas Temp. (°F)	65.00	65
Liquid Temp. (°F)	115.00	85
Capacity (BTU/hr)	21200	30400
Power (W):	2100	1690
Current (Amps):	9.75	8.05
EER(BTU/Wh):	10.11	17.97
Mass Flow (lbs/hr):	324	376
Sound Data @ 45 / 130		
Sound Power (dBA):	Avg	78 Max
Vibration mils(peak-peak):		100.0 Max
Record Date:	2021-07-12	

Mechanical	
Displacement (in^3/Rev):	1.76
Displacement (ft^3/Hr):	
Overall Length (in):	9.30
Overall Width (in):	9.09
Overall Height (in):	14.12
Mounting Length (in):	7.50
Mounting Width (in):	7.50
Mounting Height (in):	14.98
Suction Size (in),Type:	1 / 2 Stub
Discharge Size (in),Type:	3 / 8 Stub
Initial Oil Charge (oz):	35
Oil Recharge (oz):	35
Oil Type:	POE
Net Weight (lbs):	69.5
Internal Free Volume (in^3):	
Horse Power:	

*Overall compressor height on Copeland Brand Product's specified mounting grommets.

Electrical	
LRA High* (Amps):	74
LRA Low*(Amps):	
LRA Half Winding (Amps):	
MCC (Amps):	19
Max Operating Current (Amps):	
RLA, MCC/1.4(use for contactor selection)(Amps):	13.6
RLA, MCC/1.56(use for breaker & wire size selection)(Amps):	12.2
RPM:	3500
Box IP :	
UL File No:	
UL File Date:	

*Low and High refer to the low and high nominal voltage ranges for which the motor is approved.

Capacitors

Type	Part No	Low MFD	High MFD	Volts	User Description
No data available in table					

Coeff#	Capacity (Btu/hr)	Power (W)	Current (Amps)	Mass Flow (lbs/hr)
0	-3957.96138105264	2318.80241339298	6.06508051885872	104.551151373699
1	1213.7246042632	-34.2634073100331	0.17358818056787	13.0718200660992
2	256.659286719385	-25.1850825375482	-0.104170485222072	-2.0015411821846
3	5.91353123430517	-0.451159955924902	-0.00450355013813934	0.0381544522226493
4	-13.2547311164309	0.833155069062735	-0.000428542098219626	-0.150832549985571
5	-1.16817940373403	0.164877649116071	0.00145505745671617	0.041983948543955
6	0.0172084950267387	-0.00369573542824681	-8.60029417718881E-06	0.000200298596044666
7	-0.033241548326054	0.00661488827086934	4.58958099440057E-05	-0.000111599993040369
8	0.0485301172132427	-0.00421534034894921	-6.63574572819163E-06	0.0006744688394973
9	-0.003297595959582	-0.000160030425729842	-4.4605735546754E-06	-0.000234506560524888