

Air Condition Lab Calculation

In this lab, we are analyzing Hilton Air Conditioning Laboratory Unit. This air conditionr uses R-134a as the refrigerant. The dry-run uses pre-heater while wet-run uses steam injection.

Firstly: DRY RUN

Determination of Air States:

units
kJ := 1000J

Ambient pressure: $p_{atm} := 102.1 \text{ kPa}$

At Point A:

$T_{Adb} := 21.1 \text{ }^\circ\text{C}$

$T_{Awb} := 13.5 \text{ }^\circ\text{C}$

Linear Interpolation for Saturation Pressure of Water:

Saturated water temperature Table A-4, p. 890 Y. A. Cengel and M. A. Boles, "Thermodynamics An Engineering Approach," 5th ed., McGraw Hill (2006).

	$\left(\begin{array}{c} 0.6117 \\ 0.8725 \\ 1.2281 \\ 1.7057 \\ 2.3392 \\ 3.1698 \\ 4.2469 \\ 5.6291 \\ 7.3851 \\ 9.5953 \\ 12.352 \\ 15.763 \\ 19.947 \\ 25.043 \\ 31.202 \\ 38.597 \\ 47.416 \\ 57.868 \\ 70.183 \\ 84.609 \end{array} \right)$	kPa		$\left(\begin{array}{c} 0.01 + 273.15 \\ 5 + 273.15 \\ 10 + 273.15 \\ 15 + 273.15 \\ 20 + 273.15 \\ 25 + 273.15 \\ 30 + 273.15 \\ 35 + 273.15 \\ 40 + 273.15 \\ 45 + 273.15 \\ 50 + 273.15 \\ 55 + 273.15 \\ 60 + 273.15 \\ 65 + 273.15 \\ 70 + 273.15 \\ 75 + 273.15 \\ 80 + 273.15 \\ 85 + 273.15 \\ 90 + 273.15 \\ 95 + 273.15 \end{array} \right)$	K
$P_{satH2O} :=$			$T_{satH2O} :=$		

Function Definitions:

$$h_{ca}(T_{Adb}, \omega_A) := \left[T_{Adb} / ^\circ C + \omega_A \cdot (2501 + 1.805 \cdot T_{Adb} / ^\circ C) \right] \frac{\text{kJ}}{\text{kg}}$$

1) Start by finding the saturation pressure at the wet bulb temperature:

$$P_{gw} = P_{sat} @ T_{wb} \quad P_{Agw} := \text{interp}(T_{\text{satH2O}}, P_{\text{satH2O}}, T_{Awb}) \quad P_{Agw} = 1.562 \cdot \text{kPa}$$

2) Calculate the vapor pressure using Carrier's Equation:

$$P_{Av} := P_{Agw} - \frac{(P_{\text{atm}} - P_{Agw}) \cdot (T_{Adb} / ^\circ C - T_{Awb} / ^\circ C)}{1532.4 - 1.3 \cdot T_{Awb} / ^\circ C} \quad P_{Av} = 1.058 \cdot \text{kPa}$$

3) calculate the specific humidity ω :

$$\omega = 0.622 \frac{P_v}{P - P_v} \quad \omega_A := 0.622 \cdot \frac{P_{Av}}{P_{\text{atm}} - P_{Av}} \quad \omega_A = 0.0065$$

4) Determine the saturation pressure at the dry bulb temperature p_g and calculate the relative humidity ϕ :

$$P_{Ag} := \text{interp}(T_{\text{satH2O}}, P_{\text{satH2O}}, T_{Adb}) \quad P_{Ag} = 2.522 \cdot \text{kPa}$$

$$\phi = \frac{P_v}{P_g} \quad \phi_A := \frac{P_{Av}}{P_{Ag}} \quad \phi_A = 41.953 \cdot \%$$

5) Calculate the enthalpy h using the function above:

$$h_A := h_{ca}(T_{Adb}, \omega_A) \quad h_A = 37.637 \cdot \frac{\text{kJ}}{\text{kg}}$$

Determining the specific volume:

$$v = R_{\text{mix}} \cdot \frac{T}{p} \quad \text{where } R_{\text{mix}} \text{ is the specific gas constant for the mixture, which is given by:}$$

$$R_{\text{mix}} = y_a \cdot R_a + y_v \cdot R_v \quad R_a := 287 \frac{\text{J}}{\text{kg} \cdot \text{K}} \quad R_v := 461.4 \frac{\text{J}}{\text{kg} \cdot \text{K}}$$

In these equations, the subscripts "a" and "v" indicate air and water vapor, respectively, y indicates the mass fraction, and R is the specific gas constant. The mass fractions for our binary system can be expressed in terms of the specific humidity:

$$y_a = \frac{1}{1 + \omega} \quad y_v = \frac{\omega}{1 + \omega}$$

performing these calculations at Point A yields:

$$y_a := \frac{1}{1 + \omega_A} \quad y_a = 0.994 \quad y_v := \frac{\omega_A}{1 + \omega_A} \quad y_v = 0.00647$$

$$R_{A\text{mix}} := y_a \cdot R_a + y_v \cdot R_v = 288.129 \cdot \frac{\text{J}}{\text{kg} \cdot \text{K}}$$

$$v_A := R_{A\text{mix}} \cdot \frac{T_{Adb}}{P_{\text{atm}}} \quad v_A = 0.8304 \frac{\text{m}^3}{\text{kg}}$$

At Point B:

$$T_{\text{Bdb}} := 28.7^\circ\text{C}$$

$$T_{\text{Bwb}} := 15.3^\circ\text{C}$$

Function Definitions:

$$h_{\text{cb}}(T_{\text{Bdb}}, \omega_{\text{B}}) := \left[T_{\text{Bdb}} / ^\circ\text{C} + \omega_{\text{B}} \cdot (2501 + 1.805 \cdot T_{\text{Bdb}} / ^\circ\text{C}) \right] \frac{\text{kJ}}{\text{kg}}$$

Solution:

1) Start by finding the saturation pressure at the wet bulb temperature:

$$P_{\text{gw}} = P_{\text{sat}} @ T_{\text{wb}} \quad p_{\text{Bgw}} := \text{linterp}(T_{\text{satH2O}}, P_{\text{satH2O}}, T_{\text{Bwb}}) \quad p_{\text{Bgw}} = 1.744 \cdot \text{kPa}$$

2) Calculate the vapor pressure using Carrier's Equation:

$$p_{\text{Bv}} := p_{\text{Bgw}} - \frac{(p_{\text{atm}} - p_{\text{Bgw}}) \cdot (T_{\text{Bdb}} / ^\circ\text{C} - T_{\text{Bwb}} / ^\circ\text{C})}{1532.4 - 1.3 \cdot T_{\text{Bwb}} / ^\circ\text{C}} \quad p_{\text{Bv}} = 0.855 \cdot \text{kPa}$$

3) calculate the specific humidity ω :

$$\omega = 0.622 \frac{P_{\text{v}}}{P - P_{\text{v}}} \quad \omega_{\text{B}} := 0.622 \cdot \frac{p_{\text{Bv}}}{p_{\text{atm}} - p_{\text{Bv}}} \quad \omega_{\text{B}} = 0.0053$$

4) Determine the saturation pressure at the dry bulb temperature p_g and calculate the relative humidity ϕ :

$$p_{\text{Bg}} := \text{linterp}(T_{\text{satH2O}}, P_{\text{satH2O}}, T_{\text{Bdb}}) \quad p_{\text{Bg}} = 3.967 \cdot \text{kPa}$$

$$\phi = \frac{P_{\text{v}}}{P_{\text{g}}} \quad \phi_{\text{B}} := \frac{p_{\text{Bv}}}{p_{\text{Bg}}} \quad \phi_{\text{B}} = 21.544 \cdot \%$$

5) Calculate the enthalpy h using the function above:

$$h_{\text{B}} := h_{\text{cb}}(T_{\text{Bdb}}, \omega_{\text{B}}) \quad h_{\text{B}} = 42.103 \cdot \frac{\text{kJ}}{\text{kg}}$$

Determining the specific volume:

performing these calculations at Point B yields:

$$y_{\text{a}} := \frac{1}{1 + \omega_{\text{B}}} \quad y_{\text{a}} = 0.995 \quad y_{\text{v}} := \frac{\omega_{\text{B}}}{1 + \omega_{\text{B}}} \quad y_{\text{v}} = 0.00522$$

$$R_{\text{Bmix}} := y_{\text{a}} \cdot R_{\text{a}} + y_{\text{v}} \cdot R_{\text{v}} = 287.911 \cdot \frac{\text{J}}{\text{kg} \cdot \text{K}}$$

$$v_{\text{B}} := R_{\text{Bmix}} \cdot \frac{T_{\text{Bdb}}}{p_{\text{atm}}} \quad v_{\text{B}} = 0.851 \frac{\text{m}^3}{\text{kg}}$$

At Point C:

$$T_{Cdb} := 15.8 \text{ } ^\circ\text{C}$$

$$T_{Cwb} := 10.6 \text{ } ^\circ\text{C}$$

Function Definitions:

$$h_{cc}(T_{Cdb}, \omega_C) := \left[T_{Cdb} / ^\circ\text{C} + \omega_C \cdot (2501 + 1.805 \cdot T_{Cdb} / ^\circ\text{C}) \right] \frac{\text{kJ}}{\text{kg}}$$

Solution:

1) Start by finding the saturation pressure at the wet bulb temperature:

$$P_{gw} = P_{sat} @ T_{wb} \quad P_{Cgw} := \text{interp}(T_{\text{satH2O}}, P_{\text{satH2O}}, T_{Cwb}) \quad P_{Cgw} = 1.285 \cdot \text{kPa}$$

2) Calculate the vapor pressure using Carrier's Equation:

$$P_{Cv} := P_{Cgw} - \frac{(P_{\text{atm}} - P_{Cgw}) \cdot (T_{Cdb} / ^\circ\text{C} - T_{Cwb} / ^\circ\text{C})}{1532.4 - 1.3 \cdot T_{Cwb} / ^\circ\text{C}} \quad P_{Cv} = 0.94 \cdot \text{kPa}$$

3) calculate the specific humidity ω :

$$\omega = 0.622 \frac{P_v}{P - P_v} \quad \omega_C := 0.622 \cdot \frac{P_{Cv}}{P_{\text{atm}} - P_{Cv}} \quad \omega_C = 0.0058$$

4) Determine the saturation pressure at the dry bulb temperature p_g and calculate the relative humidity ϕ :

$$P_{Cg} := \text{interp}(T_{\text{satH2O}}, P_{\text{satH2O}}, T_{Cdb}) \quad P_{Cg} = 1.807 \cdot \text{kPa}$$

$$\phi = \frac{P_v}{P_g} \quad \phi_C := \frac{P_{Cv}}{P_{Cg}} \quad \phi_C = 52.03 \cdot \%$$

5) Calculate the enthalpy h using the function above:

$$h_C := h_{cc}(T_{Cdb}, \omega_C) \quad h_C = 30.423 \cdot \frac{\text{kJ}}{\text{kg}}$$

Determining the specific volume:

performing these calculations at Point C yields:

$$y_a := \frac{1}{1 + \omega_C} \quad y_a = 0.994 \quad y_v := \frac{\omega_C}{1 + \omega_C} \quad y_v = 0.00575$$

$$R_{Cmix} := y_a \cdot R_a + y_v \cdot R_v = 288.002 \cdot \frac{\text{J}}{\text{kg} \cdot \text{K}}$$

$$v_C := R_{Cmix} \cdot \frac{T_{Cdb}}{P_{\text{atm}}} \quad v_C = 0.815 \frac{\text{m}^3}{\text{kg}}$$

At Point D:

$$T_{Ddb} := 21.1\text{ }^{\circ}\text{C}$$

$$T_{Dwb} := 12.8\text{ }^{\circ}\text{C}$$

Function Definitions:

$$h_{cd}(T_{Ddb}, \omega_D) := \left[T_{Ddb} / ^{\circ}\text{C} + \omega_D \cdot (2501 + 1.805 \cdot T_{Ddb} / ^{\circ}\text{C}) \right] \frac{\text{kJ}}{\text{kg}}$$

Solution:

1) Start by finding the saturation pressure at the wet bulb temperature:

$$P_{gw} = P_{sat} @ T_{wb} \quad p_{Dgw} := \text{linterp}(T_{\text{satH2O}}, P_{\text{satH2O}}, T_{Dwb}) \quad p_{Dgw} = 1.496 \cdot \text{kPa}$$

2) Calculate the vapor pressure using Carrier's Equation:

$$p_{Dv} := p_{Dgw} - \frac{(P_{\text{atm}} - p_{Dgw}) \cdot (T_{Ddb} / ^{\circ}\text{C} - T_{Dwb} / ^{\circ}\text{C})}{1532.4 - 1.3 \cdot T_{Dwb} / ^{\circ}\text{C}} \quad p_{Dv} = 0.945 \cdot \text{kPa}$$

3) calculate the specific humidity ω :

$$\omega = 0.622 \frac{P_v}{P - P_v} \quad \omega_D := 0.622 \cdot \frac{p_{Dv}}{P_{\text{atm}} - p_{Dv}} \quad \omega_D = 0.0058$$

4) Determine the saturation pressure at the dry bulb temperature p_g and calculate the relative humidity ϕ :

$$p_{Dg} := \text{linterp}(T_{\text{satH2O}}, P_{\text{satH2O}}, T_{Ddb}) \quad p_{Dg} = 2.522 \cdot \text{kPa}$$

$$\phi = \frac{P_v}{P_g} \quad \phi_D := \frac{p_{Dv}}{p_{Dg}} \quad \phi_D = 37.458 \cdot \%$$

5) Calculate the enthalpy h using the function above:

$$h_D := h_{cd}(T_{Ddb}, \omega_D) \quad h_D = 35.849 \cdot \frac{\text{kJ}}{\text{kg}}$$

Determining the specific volume:

performing these calculations at Point D yields:

$$y_a := \frac{1}{1 + \omega_D} \quad y_a = 0.994 \quad y_v := \frac{\omega_D}{1 + \omega_D} \quad y_v = 0.00578$$

$$R_{Dmix} := y_a \cdot R_a + y_v \cdot R_v = 288.007 \cdot \frac{\text{J}}{\text{kg} \cdot \text{K}}$$

$$v_D := R_{Dmix} \cdot \frac{T_{Ddb}}{P_{\text{atm}}} \quad v_D = 0.83 \frac{\text{m}^3}{\text{kg}}$$

Mass Flow Rate of Dry Air:

The mass flow rate of dry air (m'_a) is calculated using the equation for the calibrated orifice given in the lab instructions for the psychrometrics lab.

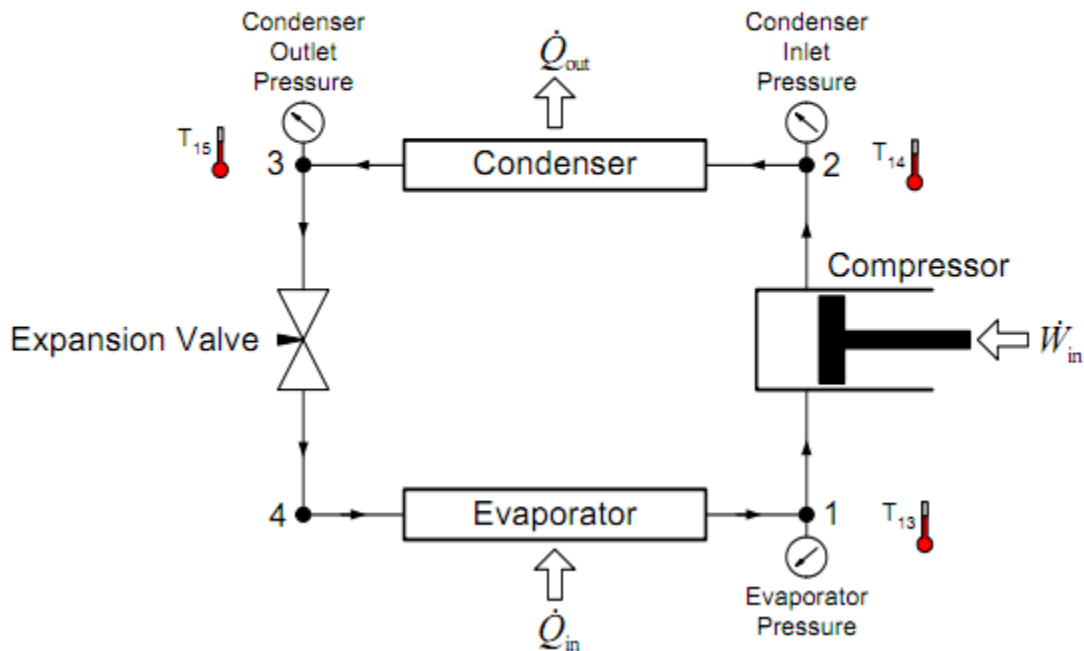
$$z := 7.5 \quad v_{Dtmp} := \frac{v_D}{\frac{m^3}{kg}} \quad v_{Dtmp} = 0.83 \quad \text{get rid of units on specific volume}$$

$$m'_a := 0.0517 \sqrt{\frac{z}{v_{Dtmp}}} \cdot \frac{kg}{s} \quad m'_a = 0.155 \frac{kg}{s} \quad \text{mass flow rate of dry air}$$

So the total mass flow rate at a point is given by: $m'_{tot} = m'_a \cdot (1 + \omega)$

Determination of Refrigerant States:

The states in the closed loop refrigeration cycle will be defined as shown in the schematic below.



Refrigerant States: R-134a

Note: from the R-134a tables, this is superheated vapor as expected. We must use double linear interpolation to determine h and s.

Point 1: Evaporator Outlet/Compressor Inlet

Measurements : $p_1 := 1.7\text{bar} + p_{\text{atm}}$

$$p_1 = 2.721 \cdot \text{bar}$$

$$T_{13} := 5.7^\circ\text{C}$$

$$T_1 := T_{13} = 5.7^\circ\text{C}$$

KLEA134a : Properties of Superheated Vapour (SI Units)

Temp C	Absolute Pressure (bar)					
	2.7			2.8		
	Satn. Temp. = 270.94 K -2.21 C			Satn. Temp. = 271.93 K -1.22 C		
	D	H	S	D	H	S
Satn.	13.351	297.2	1.728	13.826	297.8	1.728
-4	13.336	297.4	1.729			
-2	13.201	299.2	1.735	13.739	298.9	1.732
0	13.060	301.0	1.742	13.600	300.7	1.738
4	12.941	302.8	1.748	13.465	302.5	1.745
6	12.816	304.5	1.755	13.333	304.3	1.751
8	12.695	306.3	1.761	13.206	306.0	1.757
10	12.576	308.1	1.767	13.081	307.8	1.764
12	12.461	309.9	1.773	12.960	309.6	1.770

$$h_{11} := \text{linterp}\left[\left(2.7 \ 2.8\right)^T \text{bar}, \left(302.8 \ 302.5\right)^T \frac{\text{kJ}}{\text{kg}}, p_1\right]$$

$$s_{11} := \text{linterp}\left[\left(2.7 \ 2.8\right)^T \text{bar}, \left(1.748 \ 1.745\right)^T \frac{\text{kJ}}{\text{kg}\cdot\text{K}}, p_1\right]$$

$$h_{12} := \text{linterp}\left[\left(2.7 \ 2.8\right)^T \text{bar}, \left(304.5 \ 304.3\right)^T \frac{\text{kJ}}{\text{kg}}, p_1\right]$$

$$s_{12} := \text{linterp}\left[\left(2.7 \ 2.8\right)^T \text{bar}, \left(1.755 \ 1.751\right)^T \frac{\text{kJ}}{\text{kg}\cdot\text{K}}, p_1\right]$$

$$h_1 := \text{linterp}\left[\left(4 \ 6\right)^T \text{C}, \left(h_{11} \ h_{12}\right)^T, T_1\right]$$

$$s_1 := \text{linterp}\left[\left(4 \ 6\right)^T \text{C}, \left(s_{11} \ s_{12}\right)^T, T_1\right]$$

$$T_1 = 5.7^\circ\text{C}$$

$$h_1 = 304.2 \cdot \frac{\text{kJ}}{\text{kg}}$$

$$s_1 = 1.753 \cdot \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

Point 2: Compressor Outlet/Condenser Inlet

Measurements : $p_2 := 10.58 \text{ bar} + p_{\text{atm}}$

$p_2 = 11.601 \cdot \text{bar}$

$T_{14} := 68.9^\circ\text{C}$

$T_2 := T_{14} = 68.9^\circ\text{C}$

KLEA134a : Properties of Superheated Vapour (SI Units)

Temp C	11.5			12.0		
	Satn. Temp. = 317.82 K 44.67 C			Satn. Temp. = 319.47 K 46.32 C		
	D	H	S	D	H	S
Satn.	57.099	321.6	1.710	59.787	322.2	1.709
38						
40						
45	56.955	322.0	1.711			
50	54.899	327.8	1.729	58.122	326.6	1.723
55	53.088	333.4	1.747	56.110	332.4	1.741
60	51.469	339.0	1.763	54.325	338.0	1.758
65	50.006	344.5	1.780	52.721	343.6	1.774
70	48.671	349.9	1.796	51.265	349.0	1.790
75	47.444	355.2	1.811	49.932	354.4	1.806

$$h_{21} := \text{linterp}\left[\left(11.5 \quad 12\right)^T \text{ bar}, \left(344.5 \quad 343.6\right)^T \frac{\text{kJ}}{\text{kg}}, p_2\right]$$

$$s_{21} := \text{linterp}\left[\left(11.5 \quad 12\right)^T \text{ bar}, \left(1.780 \quad 1.774\right)^T \frac{\text{kJ}}{\text{kg}\cdot\text{K}}, p_2\right]$$

$$h_{22} := \text{linterp}\left[\left(11.5 \quad 12\right)^T \text{ bar}, \left(349.9 \quad 349.0\right)^T \frac{\text{kJ}}{\text{kg}}, p_2\right]$$

$$s_{22} := \text{linterp}\left[\left(11.5 \quad 12\right)^T \text{ bar}, \left(1.796 \quad 1.790\right)^T \frac{\text{kJ}}{\text{kg}\cdot\text{K}}, p_2\right]$$

$$h_2 := \text{linterp}\left[\left(65 \quad 70\right)^T ^\circ\text{C}, \left(h_{21} \quad h_{22}\right)^T, T_2\right]$$

$$s_2 := \text{linterp}\left[\left(65 \quad 70\right)^T ^\circ\text{C}, \left(s_{21} \quad s_{22}\right)^T, T_2\right]$$

$T_2 = 68.9^\circ\text{C}$

$h_2 = 348.53 \cdot \frac{\text{kJ}}{\text{kg}}$

$s_2 = 1.791 \cdot \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$

Point 3: Condenser Outlet/Expansion Valve Inlet

Measurements : $p_3 := 10.33\text{bar} + p_{\text{atm}}$ $p_3 = 11.351\cdot\text{bar}$

$T_{15} := 38.3\text{ }^\circ\text{C}$ $T_3 := T_{15} = 38.3\text{ }^\circ\text{C}$

From the R134a Tables, in the saturated tables, the saturation pressure at the measured temperature of 38.0 deg C is 9.63052 bar which is below the measured pressure. Therefore, the refrigerant is subcooled as expected and we use the subcooled liquid approximation to determine h and s at this point.

Temp C	Absolute Pressure bar	Density		Enthalpy			Entropy	
		kg/m ³	kg/m ³	kJ/kg			kJ/(kg K)	
		Liquid	Vapour	Liquid	Latent	Vapour	Liquid	Vapour
30	7.70132	1187.5	37.517	141.736	173.156	314.892	1.14354	1.71473
31	7.92501	1183.5	38.634	143.190	172.193	315.383	1.14826	1.71441
32	8.15355	1179.6	39.779	144.649	171.220	315.869	1.15299	1.71409
33	8.38701	1175.6	40.953	146.112	170.239	316.351	1.15771	1.71377
34	8.62545	1171.5	42.157	147.580	169.247	316.827	1.16243	1.71346
35	8.86896	1167.5	43.391	149.053	168.246	317.299	1.16715	1.71314
36	9.11759	1163.4	44.658	150.530	167.235	317.765	1.17187	1.71282
37	9.37142	1159.2	45.956	152.013	166.213	318.226	1.17659	1.71250
38	9.63052	1155.1	47.288	153.500	165.181	318.681	1.18130	1.71217
39	9.89496	1150.9	48.654	154.993	164.138	319.131	1.18602	1.71185
40	10.1648	1146.7	50.055	156.491	163.084	319.575	1.19073	1.71152
41	10.4401	1142.4	51.492	157.994	162.019	320.013	1.19545	1.71119
42	10.7210	1138.1	52.967	159.503	160.942	320.445	1.20017	1.71085
43	11.0076	1133.7	54.479	161.017	159.853	320.870	1.20488	1.71051

Approximate to the Saturated liquid

$$h_3 := \text{linterp}\left[(38 \text{ }^\circ\text{C}, (153.500 \text{ } \frac{\text{kJ}}{\text{kg}}), (39 \text{ }^\circ\text{C}, (154.993 \text{ } \frac{\text{kJ}}{\text{kg}})), T_3\right]$$

$$s_3 := \text{linterp}\left[(38 \text{ }^\circ\text{C}, (1.18130 \text{ } \frac{\text{kJ}}{\text{kg}\cdot\text{K}}), (39 \text{ }^\circ\text{C}, (1.18602 \text{ } \frac{\text{kJ}}{\text{kg}\cdot\text{K}})), T_3\right]$$

$$T_3 = 38.3\text{ }^\circ\text{C}$$

$$h_3 = 153.948 \cdot \frac{\text{kJ}}{\text{kg}}$$

$$s_3 = 1.183 \cdot \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

Point 4: Expansion Valve Outlet/Evaporator Inlet

Measurements : We don't have any, so we make assumptions

we know that we are under the vapor dome. Assuming that there is no pressure drop across the evaporator, then

$$p_4 := p_1 \quad p_4 = 2.721 \cdot \text{bar}$$

the adiabatic throttling process from 3 to 4 is a constant enthalpy process, therefore:

$$h_4 := h_3 \quad h_4 = 153.948 \cdot \frac{\text{kJ}}{\text{kg}}$$

since we are underneath the vapor dome, we are at the same saturation temperature for the given pressure. From the saturation tables:

-3	2.62250
-2	2.72136

$$T_4 := (-3)^\circ\text{C} + 1 \cdot \Delta^\circ\text{C} \cdot \frac{(2.721 - 2.62250)}{(2.72136 - 2.62250)} = -2.004^\circ\text{C} \quad T_4 = -2.004^\circ\text{C}$$

determination of quality in order to determine entropy:

KLEA134a SATURATION PROPERTIES (SI Units)

Temp C	Absolute Pressure bar	Density		Enthalpy			Entropy	
		kg/m ³	kg/m ³	kJ/kg			kJ/(kg·K)	
		Liquid	Vapour	Liquid	Latent	Vapour	Liquid	Vapour
-5	2.43310	1311.5	12.083	93.351	202.236	295.588	0.97557	1.72977
-4	2.52643	1308.2	12.526	94.675	201.506	296.181	0.98047	1.72915
-3	2.62250	1305.0	12.983	96.002	200.771	296.772	0.98537	1.72855
-2	2.72136	1301.7	13.453	97.331	200.031	297.362	0.99025	1.72796
-1	2.82307	1298.4	13.936	98.664	199.286	297.950	0.99513	1.72739

$$h_{f4} := 96.002 \frac{\text{kJ}}{\text{kg}} + \left(97.331 \frac{\text{kJ}}{\text{kg}} - 96.002 \frac{\text{kJ}}{\text{kg}} \right) \cdot \frac{(2.721 - 2.62250)}{(2.72136 - 2.62250)} = 97.326 \cdot \frac{\text{kJ}}{\text{kg}}$$

$$h_{g4} := 296.772 \frac{\text{kJ}}{\text{kg}} + \left(297.362 \frac{\text{kJ}}{\text{kg}} - 296.772 \frac{\text{kJ}}{\text{kg}} \right) \cdot \frac{(2.721 - 2.62250)}{(2.72136 - 2.62250)} = 297.36 \cdot \frac{\text{kJ}}{\text{kg}}$$

$$s_{f4} := 0.98537 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} + \left(0.99025 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} - 0.98537 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \right) \cdot \frac{(2.721 - 2.62250)}{(2.72136 - 2.62250)} = 0.99 \cdot \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

$$s_{g4} := 1.72855 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} + \left(1.72796 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} - 1.72855 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \right) \cdot \frac{(2.721 - 2.62250)}{(2.72136 - 2.62250)} = 1.728 \cdot \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

$$x_4 := \frac{(h_4 - h_{f4})}{(h_{g4} - h_{f4})} \quad x_4 = 0.283$$

$$s_4 := s_{f4} + x_4 \cdot (s_{g4} - s_{f4}) \quad s_4 = 1.199 \cdot \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

T-s Diagram for Refrigerant:

1. Compressor Inlet stays the same
2. Compressor outlet/Condenser Inlet - stays the same
- 2.a Condenser condenses to saturated vapor at condenser pressure

$$p_{2a} := p_2 \quad p_{2a} = 11.601 \cdot \text{bar}$$

Temp C	Absolute Pressure bar	Density		Enthalpy			Entropy	
		kg/m ³	kg/m ³	kJ/kg			kJ/(kg K)	
		Liquid	Vapour	Liquid	Latent	Vapour	Liquid	Vapour
44	11.2998	1129.4	56.031	162.537	158.752	321.289	1.20960	1.71016
45	11.5978	1124.9	57.623	164.062	157.639	321.701	1.21432	1.70981
46	11.9017	1120.5	59.256	165.593	156.513	322.106	1.21904	1.70945
47	12.2115	1116.0	60.933	167.130	155.374	322.504	1.22376	1.70908

$$T_{2a} := 45 \text{ } ^\circ\text{C} + (46 \text{ } ^\circ\text{C} - 45 \text{ } ^\circ\text{C}) \cdot \left[\frac{(11.601 - 11.5978)}{(11.9017 - 11.5978)} \right] \quad T_{2a} = 45.011 \cdot ^\circ\text{C} \quad \text{saturation temp}$$

$$s_{2a} := 1.70981 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} + \left(1.70945 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} - 1.70981 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \right) \cdot \frac{(11.601 - 11.5978)}{(11.9017 - 11.5978)} \quad s_{2a} = 1.70981 \cdot \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \quad \text{saturated vapor}$$

- 2.b Condenser condenses from saturated vapor to saturated liquid at constant temperature and pressure

$$p_{2b} := p_{2a} \quad T_{2b} := T_{2a} \quad T_{2b} = 45.011 \cdot ^\circ\text{C}$$

$$s_{2b} := 1.21432 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} + \left(1.21904 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} - 1.21432 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \right) \cdot \frac{(11.601 - 11.5978)}{(11.9017 - 11.5978)} \quad s_{2b} = 1.2144 \cdot \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \quad \text{saturated liquid}$$

3. Condenser Outlet/Expansion Valve Inlet - stays the same
4. Expansion valve outlet/Evaporator inlet - stays the same
- 4.a Refrigerant is heated at constant pressure and temperature to a saturated vapor in the evaporator

$$p_{4a} := p_4 \quad p_{4a} = 2.721 \cdot \text{bar} \quad T_{4a} := T_4 \quad T_{4a} = -2.004 \cdot ^\circ\text{C}$$

KLEA134a SATURATION PROPERTIES (SI Units)

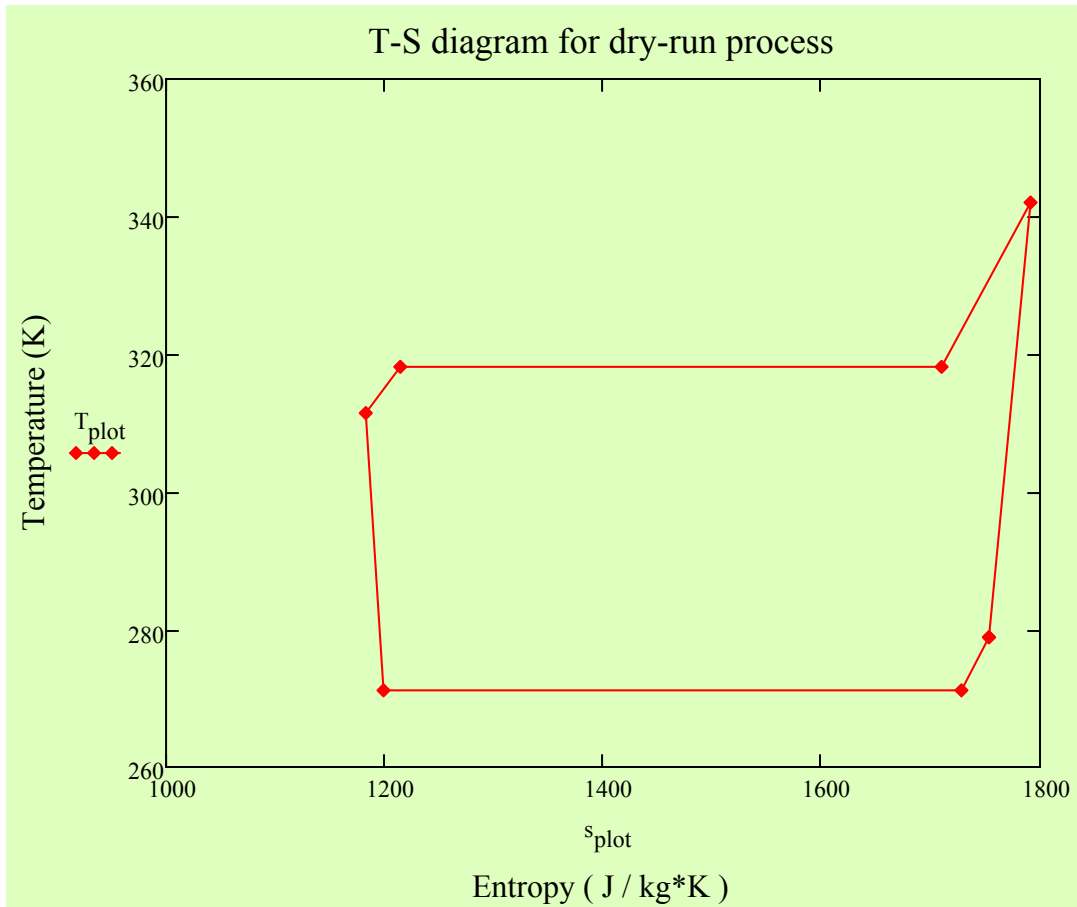
Temp C	Absolute Pressure bar	Density		Enthalpy			Entropy	
		kg/m ³	kg/m ³	kJ/kg			kJ/(kg K)	
		Liquid	Vapour	Liquid	Latent	Vapour	Liquid	Vapour
-5	2.43310	1311.5	12.083	93.351	202.236	295.588	0.97557	1.72977
-4	2.52643	1308.2	12.526	94.675	201.506	296.181	0.98047	1.72915
-3	2.62250	1305.0	12.983	96.002	200.771	296.772	0.98537	1.72855
-2	2.72136	1301.7	13.453	97.331	200.031	297.362	0.99025	1.72796
-1	2.82307	1298.4	13.936	98.664	199.286	297.950	0.99513	1.72739

$$s_{4a} := 1.72855 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} + (1.72796 - 1.72855) \cdot \frac{(3 - 2.004)}{(3 - 2)} \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

$$s_{4a} = 1.727962 \cdot \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \text{ saturated vapor}$$

T-s Diagram

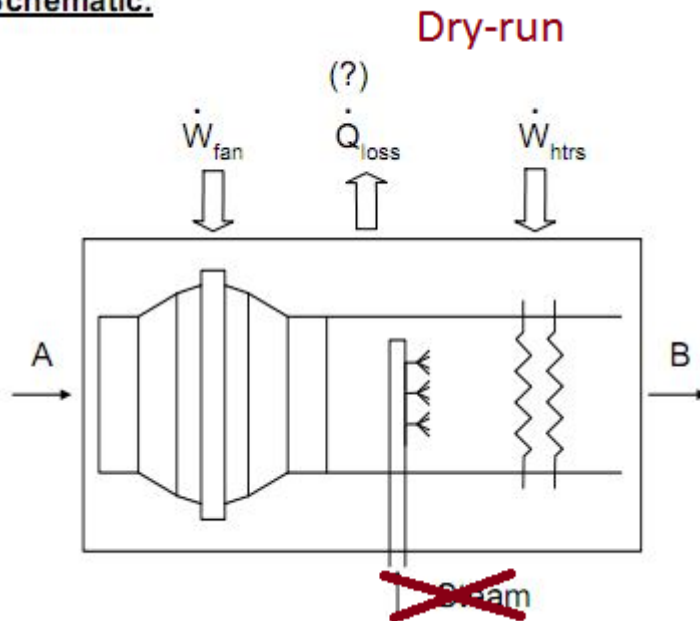
$$T_{\text{plot}} := (T_1 \ T_2 \ T_{2a} \ T_{2b} \ T_3 \ T_4 \ T_{4a} \ T_1)^T \quad s_{\text{plot}} := (s_1 \ s_2 \ s_{2a} \ s_{2b} \ s_3 \ s_4 \ s_{4a} \ s_1)^T$$



Control-Volume Analysis:

Mass and energy balance A to B:

Schematic:



conservation of mass at steady state: mass flow rate in = mass flow rate out

$$m'_A + m'_{stm} = m'_B \quad m'_{stm} = m'_B - m'_A = 0$$

$$m'_A := m'_a \cdot (1 + \omega_A) = 0.1564 \frac{\text{kg}}{\text{s}}$$

$$m'_B := m'_a \cdot (1 + \omega_B) = 0.1562 \frac{\text{kg}}{\text{s}}$$

$$m'_{stm} := m'_a \cdot (\omega_B - \omega_A) = -0.000196 \frac{\text{kg}}{\text{s}} \quad \text{which almost equals to 0, means that there is no steam injection into the process}$$

$$m'_{stm} := 0$$

conservation of energy at steady state: rate of energy in = rate of energy out

$$m'_a \cdot h_A + m'_{stm} \cdot h_{stm} + W'_{fan} + W'_{htrs} = m'_a \cdot h_B + Q'_{loss}$$

the fan power can be obtained by using the fan power curve (Figure 3 in psychrometrics lab) and the measured fan supply voltage:

$$v_F := 165V$$

$$W'_{fan} := 162W$$

***Figure 3 in psychrometrics lab shown below

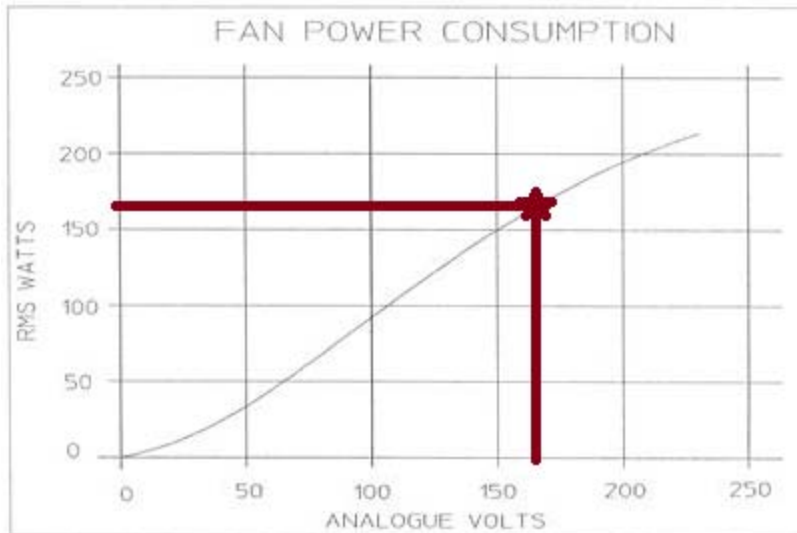


Figure 3: Fan power versus fan supply voltage [1]

the first pre-heater is energized. The heater can be determined using the measured line voltage and the known resistance of the 1st pre-heater (table 1 in psychrometrics lab)

$$V_L := 210V$$

$$R_p := 47.2\Omega$$

**Table 1 in psychrometrics lab

1 st Pre-heater, 1kW	R_p	47.2 Ω
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$$W'_{hts} := \frac{V_L^2}{R_p}$$

$$W'_{hts} = 934.322 W$$

We can now estimate the heat loss between A and B using the energy balance:

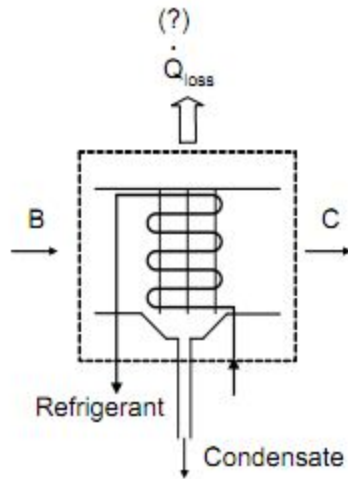
$$Q'_{lossAB} := m'_a \cdot h_A + W'_{fan} + W'_{hts} - m'_a \cdot h_B$$

$$Q'_{lossAB} = 402.304 W$$

the calculated value for "heat loss" results from several different effects including heat loss through the duct walls, inaccurate measurements, inaccuracies in calculated values for the enthalpy of air, ect.

Mass and energy balance B to C:

Schematic:



Between B and C - we are removing energy from the air and adding energy to the refrigerant in the evaporator. The data also indicated that there is no condensate formed.

Conservation of Mass at Steady State: mass flow rate in = mass flow rate out

Note: the refrigerant doesn't interact with the condensate

$$m'_B = m'_C + m'_{cond} \quad m'_{cond} = m'_B - m'_C$$

$$m'_B = 0.156 \frac{\text{kg}}{\text{s}}$$

$$m'_C := m'_a \cdot (1 + \omega_C) = 0.156 \frac{\text{kg}}{\text{s}}$$

$$m'_{cond} := m'_a \cdot (\omega_B - \omega_C) = -0.0000825 \frac{\text{kg}}{\text{s}} \quad \textbf{Estimated condensate flow rate}$$

which is very close to 0 Thus: $m'_{cond} := 0$

Observed condensate flow rate:

Volume flow rate:

$$V'_{condObs} := 0 \frac{\text{mL}}{10\text{min}} = 0 \quad \text{which matches to the value just calculated above}$$

Approximate density: $\rho_{cond} := 1000 \frac{\text{kg}}{\text{m}^3}$

Mass flow rate: $m'_{condObs} := V'_{condObs} \cdot \rho_{cond} = 0$

Note the difference between the estimated condensate flow rate and the observed rate are caused by many different effects including measurement errors, water retention on the evaporation fins, re-entrainment of water into the air stream, ect.

Conservation of energy at steady state: rate of energy in = rate of energy out

for our energy balance from B to C, we are concerned with the refrigerant entering (state 4) and exiting (state 1), The complete energy balance is:

$$m'_a \cdot h_B + m'_{ref} \cdot h_4 = m'_a \cdot h_C + m'_{cond} \cdot h_{cond} + m'_{ref} \cdot h_1 + Q'_{loss}$$

$$\Rightarrow m'_a \cdot h_B + m'_{ref} \cdot h_4 = m'_a \cdot h_C + m'_{ref} \cdot h_1 + Q'_{loss}$$

so there is no need to find the h_{cond}

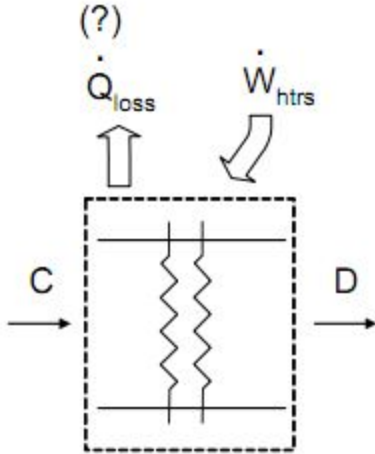
Measured Refrigerant Flow Rate: $m'_{ref} := 14.5 \frac{\text{gm}}{\text{s}}$

$$Q'_{lossBC} := m'_a \cdot h_B + m'_{ref} \cdot h_4 - m'_a \cdot h_C - m'_{ref} \cdot h_1$$

$Q'_{lossBC} = -363.532 \text{ W}$ appears to indicate heat transfer into control volume

Mass and Energy Balance C to D:

Schematic:



Between C and D - we are adding energy to the air via the first re-heater.

$$m'_C = m'_D$$

$$m'_C = m'_a \cdot (1 + \omega_C) \quad m'_C = 0.1563 \frac{\text{kg}}{\text{s}}$$

$$m'_D := m'_a \cdot (1 + \omega_D) = 0.1563 \frac{\text{kg}}{\text{s}}$$

Therefore conservation of mass tells us that the specific humidity should not change between C and D, which makes sense because we are not adding water to or removing water from the air. Any difference in the specific humidities would be probably caused by measurement error.

$$\omega_C = 0.005781$$

$$\omega_D = 0.0058087$$

Conservation of energy at Steady-State: rate of energy in = rate of energy out

$$m'_a \cdot h_C + W_{\text{rhtrs}} = m'_a \cdot h_D + Q_{\text{loss}}$$

The first re-heater is energized. The heater power can be determined using the measured line voltage and the known resistance of the 1st re-heater.

$$V_L = 210 \text{ V}$$

and

$$R_r := 46.8 \Omega$$

1 st Re-heater, 1kW	R_r	46.8 Ω
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$$W'_{\text{rhtrs}} := \frac{V_L^2}{R_r}$$

$$W'_{\text{rhtrs}} = 942.308 \text{ W}$$

$$Q'_{\text{lossCD}} := m'_a \cdot h_C + W'_{\text{rhtrs}} - m'_a \cdot h_D$$

$$Q'_{\text{lossCD}} = 99.128 \text{ W}$$

Refrigeration Effect/Capacity:

Q'_L : rate of heat transfer to the refrigerant in the evaporator

$$Q'_L := m'_{\text{ref}} \cdot (h_1 - h_4) \quad Q'_L = 2178.653 \text{ W}$$

$$\text{Ton} := 12000 \frac{\text{BTU}}{\text{hr}} \quad Q'_L = 0.619 \cdot \text{Ton}$$

COP (Coefficient of Performance):

$$\text{COP} = \frac{\text{Desired Output}}{\text{Required Input}} = \frac{\text{Refrigeration Effect}}{\text{Net Power Input}} = \frac{Q'_L}{W'_{\text{netin}}}$$

Note that the net power input is generally based on the total electric power required to run the refrigeration cycle, which for our case would include the compressor power and the power for the condenser fan. At this time, we have no way to determine the condenser fan power, so we will neglect it. We could try to use the power imparted to the fluid in the compressor as the net power input. In that case,

$$W'_{\text{netinFluid}} := m'_{\text{ref}} \cdot (h_2 - h_1) \quad W'_{\text{netinFluid}} = 642.79 \text{ W}$$

$$\text{COP}_{\text{netinFluid}} := \frac{Q'_L}{W'_{\text{netinFluid}}} \quad \text{COP}_{\text{netinFluid}} = 3.389$$

note that the value obtained for Cop is very high when using the fluid power. In order to use the electric power to the compressor, we need the line voltage (we have it), the compressor current (I_c , which we don't have), and the power factor (pf, which is the cosine of the phase angle) for the compressor motor under our operating conditions (which we don't have). The resulting real electric power that is consumed by the compressor is given by:

$$W'_{\text{comp}} = V_L \cdot I_C \cdot \text{pf}$$

The manufacturer states that "typical" values during tests are:

$$I_C := 7 \text{ A} \quad \text{and} \quad 0.5 \leq \text{pf} \leq 0.8$$

The resulting maximum and minimum compressor powers and their associated COP's are:

$$\text{pf}_{\text{max}} := 0.8 \quad W'_{\text{compMax}} := V_L \cdot I_C \cdot \text{pf}_{\text{max}} \quad W'_{\text{compMax}} = 1.176 \cdot \text{kW}$$

$$\text{COP}_{\text{low}} := \frac{Q'_L}{W'_{\text{compMax}}} \quad \text{COP}_{\text{low}} = 1.853$$

$$\text{pf}_{\text{min}} := 0.5 \quad W'_{\text{compMin}} := V_L \cdot I_C \cdot \text{pf}_{\text{min}} \quad W'_{\text{compMin}} = 0.735 \cdot \text{kW}$$

$$\text{COP}_{\text{high}} := \frac{Q'_L}{W'_{\text{compMin}}} \quad \text{COP}_{\text{high}} = 2.964$$

EER:

$$\text{EER} = \frac{\text{Refrigeration Effect in Btu/hr}}{\text{Net Power Input in Watts}} = 3.413 \cdot \text{COP}$$

$$\text{EER}_{\text{high}} := 3.413 \cdot \text{COP}_{\text{high}} \cdot \frac{\text{BTU}}{\text{W} \cdot \text{hr}} = 10.117 \cdot \frac{\text{BTU}}{\text{W} \cdot \text{hr}}$$

$$\text{EER}_{\text{low}} := 3.413 \cdot \text{COP}_{\text{low}} \cdot \frac{\text{BTU}}{\text{W} \cdot \text{hr}} = 6.323 \cdot \frac{\text{BTU}}{\text{W} \cdot \text{hr}}$$

Overall Compressor Efficiency:

The overall compressor efficiency is just the ratio of the power imparted to the fluid by the compressor to the real electric power consumed by the compressor. Since we made some assumptions to get the electric power to the compressor, we could get different values for the compressor efficiency.

$$\eta_{\text{compMax}} := \frac{W'_{\text{netinFluid}}}{W'_{\text{compMin}}}$$

$$\eta_{\text{compMax}} = 87.454\%$$

$$\eta_{\text{compMin}} := \frac{W'_{\text{netinFluid}}}{W'_{\text{compMax}}}$$

$$\eta_{\text{compMin}} = 54.659\%$$