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10/1/18

Thermal Systems HW #4

Quantify and Compare Refrigeration Cycles

Table of Values

COP_Summer	COP_Winter	Mass_Flow_Summer (kg/s)	Mass_Flow_Winter (kg/s)
4.82	10.5	.030	.025

Compressor_Power_Summer (J/s)	Compressor_Power_Winter (J/s)
1,037	475.4

Description of Values

From the values calculated above, we are able to analyze the outcome of the refrigeration cycle during the Summer and Winter months in Durham, NH. The outside environment during the summer months was calculated to be 303 Kelvin, while the winter was 283 Kelvin. From this difference in outside temperature, it changed the overall refrigeration cycle, altering heavily the COP, Mass Flow Rate needed, and the compressor power. The data shows that the COP from the summer to the winter more than doubles when the outside temperature is closer to the temperature desired for cooling. By having a better COP, it is expected that the mass flow rate needed decreases to still maintain the same desired cooled temperature. This also alters the required power the compressor needs to experience, allowing the amount of J/s to decrease in the winter months due to less of a temperature difference from the outside environment. The graphs below detail the overall cycle change for the variation of outside temperatures Durham, NH could encounter during a whole year.

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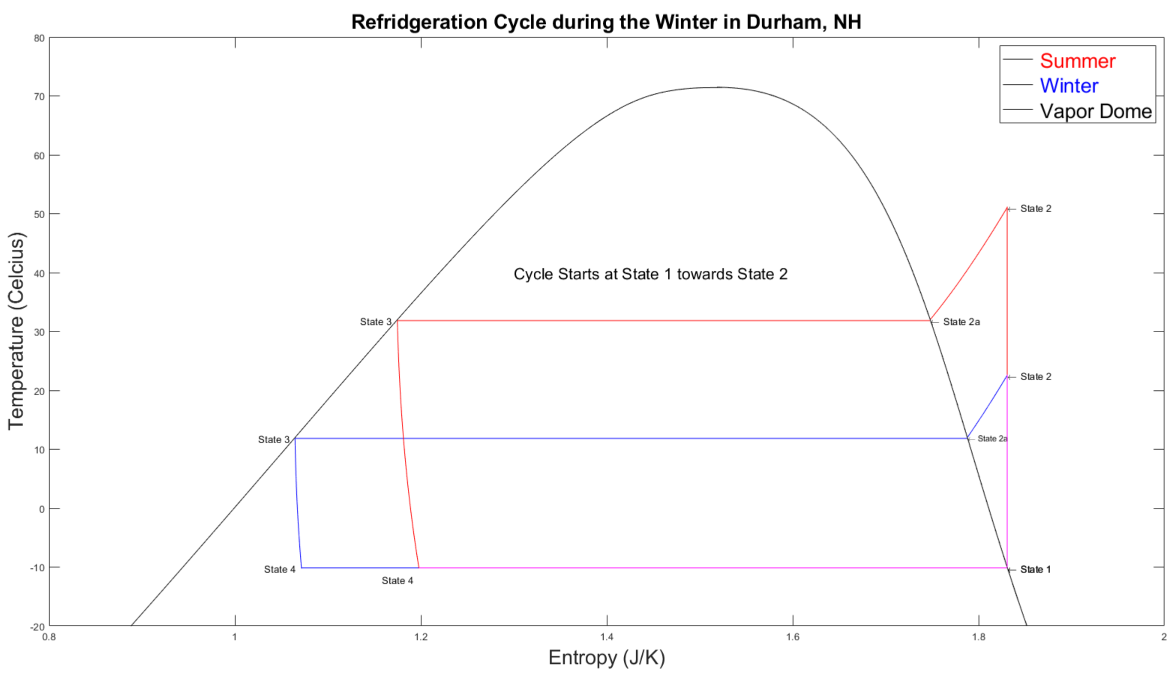

Figure 1- The Temperature vs. Entropy graph for two different refrigeration cycles during the Summer and Winter months in Durham, NH.

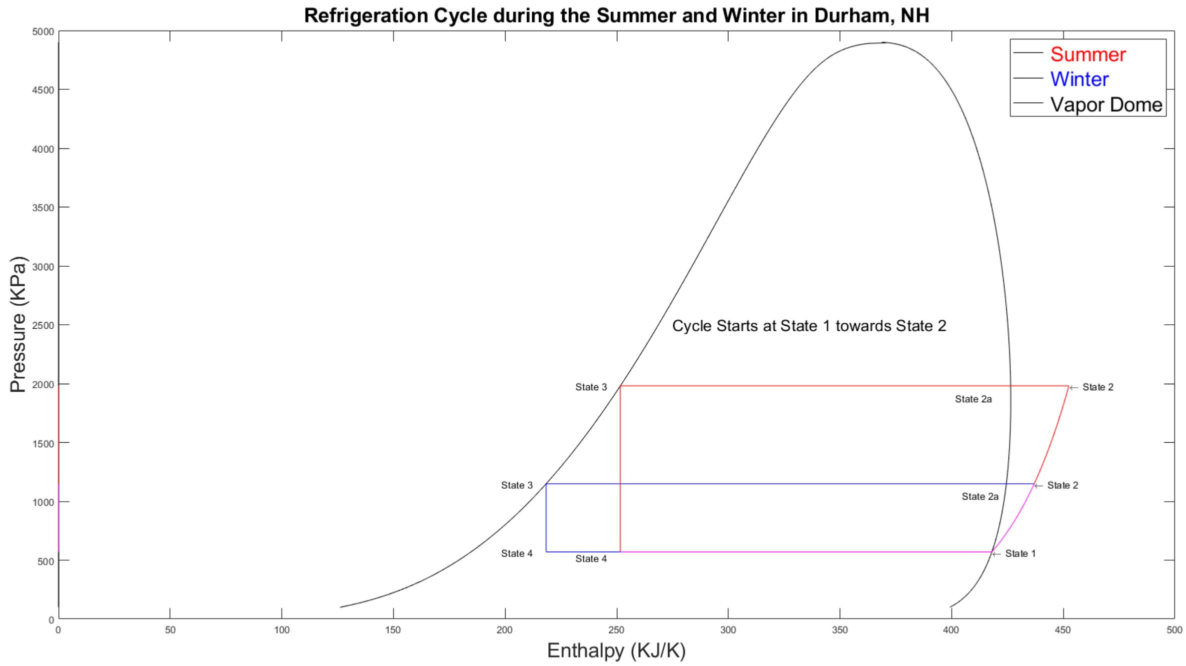

Figure 2- The Pressure vs. Enthalpy graph for two different refrigeration cycles during the Summer and Winter months in Durham, NH.

MATLAB CODE

```
clear all; close all
clc;

%Problem Statement
% %A refrigerator in a meat warehouse located in Durham, NH has a cooling capacity of 5kW. It must
maintain
% the cold space at -15?C throughout the entire year. Quantify and compare the flow rate required,
compressor
% power, and coefficient of performance (COP) for the best and worst case scenarios, assuming an
ideal, standard
% vapor compression refrigeration cycle with ?TL = 5?C and ?TH = 2?C. Plot the two scenarios on
both a T-s
% and a P-h diagram (include the vapor dome). Label the state points and indicate the cycle
direction. Note that
% ?TL and ?TH refer to the temperature differences between the cycle and environments needed for
the heat transfer.
% Please submit a single pdf file with the solution. You need to include all the figures and the
entire code in the file.
% The code should follow the solution.



%%%%%%%%%%%%%
% Constants for the Refridgeration Cycle for Durham, NH
%%%%%%%%%%%%%
```

```
T_L = 5; % Kelvin - Amount of temperature away from the Evaporator Process
T_H = 2; % Kevlin - Amount of temperature away from the second part of the Condensor Process
Cold_Space = 273-15; % Kelvin - Temperature of Cold Space of Refridgerator
Hot_Space_Summer  = 273 + 30; % Hottest recorded temperature of Durham NH in the Summer
Hot_Space_Winter  = 273 + 10; % Hottest recorded temperature of Durham NH in the Winter
T_Outside = linspace(250,Hot_Space_Summer,1000); % Kelvin - Record high and low temperatures in
Durham that the outside temperature would reach, 1000 Length Array



%%%%%%%%%%%%%
% Location 1 - Between Evaporator and Compressor
%%%%%%%%%%%%%

% Finding all values of the fluid at location 1
Q_1 = 1; % Saturated Vapor
T_1 = Cold_Space + T_L; % Temperature from 4 to 1
P_1 = CoolProp.PropsSI('P', 'T', T_1, 'Q', Q_1, 'R410a');
H_1 = CoolProp.PropsSI('H', 'T', T_1, 'Q', Q_1, 'R410a');
U_1 = CoolProp.PropsSI('U', 'T', T_1, 'Q', Q_1, 'R410a');
S_1 = CoolProp.PropsSI('S', 'T', T_1, 'Q', Q_1, 'R410a');



%%%%%%%%%%%%%
% Location 3 - Between Condensor and Expansion Valve - Saturated Liquid
%%%%%%%%%%%%%

% Finding all values of the fluid at location 3
Q_3 = 0; % Saturated Liquid
T_3_Summer = Hot_Space_Summer + T_H; % Temperature from 4 to 1
P_3_Summer = CoolProp.PropsSI('P', 'T', T_3_Summer, 'Q', Q_3, 'R410a');
H_3_Summer = CoolProp.PropsSI('H', 'T', T_3_Summer, 'Q', Q_3, 'R410a');
U_3_Summer = CoolProp.PropsSI('U', 'T', T_3_Summer, 'Q', Q_3, 'R410a');
S_3_Summer = CoolProp.PropsSI('S', 'T', T_3_Summer, 'Q', Q_3, 'R410a');

T_3_Winter = Hot_Space_Winter + T_H; % Temperature from 4 to 1
P_3_Winter = CoolProp.PropsSI('P', 'T', T_3_Winter, 'Q', Q_3, 'R410a');
H_3_Winter = CoolProp.PropsSI('H', 'T', T_3_Winter, 'Q', Q_3, 'R410a');
U_3_Winter = CoolProp.PropsSI('U', 'T', T_3_Winter, 'Q', Q_3, 'R410a');
S_3_Winter = CoolProp.PropsSI('S', 'T', T_3_Winter, 'Q', Q_3, 'R410a');



%%%%%%%%%%%%%
% Location 2 - Between Condensor and Expansion Valve Super-Heated Vapor
%%%%%%%%%%%%%

% Finding all values of the fluid at location 2
S_2_Summer = S_1; % Constant Entropy
P_2_Summer = P_3_Summer; % Constant Pressure Isobar
T_2_Summer = CoolProp.PropsSI('T', 'P', P_2_Summer, 'S', S_2_Summer, 'R410a');
H_2_Summer = CoolProp.PropsSI('H', 'P', P_2_Summer, 'S', S_2_Summer, 'R410a');
U_2_Summer = CoolProp.PropsSI('U', 'P', P_2_Summer, 'S', S_2_Summer, 'R410a');
```

```
P_2_Winter = P_3_Winter; % Constant Pressure Isobar
S_2_Winter = S_1; % Constant Entropy
T_2_Winter = CoolProp.PropsSI('T', 'P', P_2_Winter, 'S', S_2_Winter, 'R410a');
H_2_Winter = CoolProp.PropsSI('H', 'P', P_2_Winter, 'S', S_2_Winter, 'R410a');
U_2_Winter = CoolProp.PropsSI('U', 'P', P_2_Winter, 'S', S_2_Winter, 'R410a');



%%%%%%%%%%%%%
% Location 2a - On Vapor Dome During the process 2 to 3 in condensor
%%%%%%%%%%%%%

% Finding all values of the fluid at location 2a
Q_2a=1; % On Vapor Dome as Saturdated Vapor
P_2a_Summer = P_2_Summer; % Isobar = Constant Pressure
T_2a_Summer = T_3_Summer; % Constant Temperature from T3
S_2a_Summer = CoolProp.PropsSI('S', 'P', P_2a_Summer, 'Q', Q_2a, 'R410a');
H_2a_Summer = CoolProp.PropsSI('H', 'P', P_2a_Summer, 'Q', Q_2a, 'R410a');
U_2a_Summer = CoolProp.PropsSI('U', 'P', P_2a_Summer, 'Q', Q_2a, 'R410a');


P_2a_Winter = P_2_Winter; % Isobar = Constant Pressure
T_2a_Winter = T_3_Winter; % Constant Temperature from T3
S_2a_Winter = CoolProp.PropsSI('S', 'P', P_2a_Winter, 'Q', Q_2a, 'R410a');
H_2a_Winter = CoolProp.PropsSI('H', 'P', P_2a_Winter, 'Q', Q_2a, 'R410a');
U_2a_Winter = CoolProp.PropsSI('U', 'P', P_2a_Winter, 'Q', Q_2a, 'R410a');



%%%%%%%%%%%%%
% Location 4 - Mixture between the expansion valve and evaporator
%%%%%%%%%%%%%

% Finding all values of the fluid at location 4
T_4 = T_1; % Constant Temperature from 4 to 1 Process
H_4_Summer = H_3_Summer; % Expansion Valve is ~ constant enthalpy process
P_4_Summer = P_1; % Isobaric Process
U_4_Summer = CoolProp.PropsSI('U', 'P', P_4_Summer, 'H', H_4_Summer, 'R410a');
S_4_Summer = CoolProp.PropsSI('S', 'P', P_4_Summer, 'H', H_4_Summer, 'R410a');

H_4_Winter = H_3_Winter; % Expansion Valve is ~ constant enthalpy process
P_4_Winter = P_1; % Isobaric Process
U_4_Winter = CoolProp.PropsSI('U', 'P', P_4_Winter, 'H', H_4_Winter, 'R410a');
S_4_Winter = CoolProp.PropsSI('S', 'P', P_4_Winter, 'H', H_4_Winter, 'R410a');



%%%%%%%%%%%%%
% Calculations of the Vapor Dome for the Refridgeration Cycle
% Will be plotted as a T-s and P-h Diagram
% Two curves will be plotted for each graph, one for the Saturated Liquid and one for Saturdated
Vapor Sections
%%%%%%%%%%%%%
```

```
% Constant Variables and Pressure Array to Calculate Graph Values
Q_SL = 0; % Saturated Liquid
Q_SV = 1; % Saturated Vapor
P_SL_SV = linspace(100000,4900000,1000);  % Pressures for the Saturated Liquid Curve

T_SL = zeros(length(P_SL_SV));
S_SL = zeros(length(P_SL_SV));
H_SL = zeros(length(P_SL_SV));
T_SV = zeros(length(P_SL_SV));
S_SV = zeros(length(P_SL_SV));
H_SV = zeros(length(P_SL_SV));


% Looping 1000 times to provide values for the Vapor Dome Curves for T, s and h. P array will be
graphed with them
for index=1:1000
    T_SL(index) = CoolProp.PropsSI('T', 'P', P_SL_SV(index), 'Q', Q_SL, 'R410a') -273;
    S_SL(index) = CoolProp.PropsSI('S', 'P', P_SL_SV(index), 'Q', Q_SL, 'R410a');
    H_SL(index) = CoolProp.PropsSI('H', 'P', P_SL_SV(index), 'Q', Q_SL, 'R410a');
    T_SV(index) = CoolProp.PropsSI('T', 'P', P_SL_SV(index), 'Q', Q_SV, 'R410a') -273;
    S_SV(index) = CoolProp.PropsSI('S', 'P', P_SL_SV(index), 'Q', Q_SV, 'R410a');
    H_SV(index) = CoolProp.PropsSI('H', 'P', P_SL_SV(index), 'Q', Q_SV, 'R410a');
end


%%%%%%%%%%%%%
% Calculations of Every Point during the Refridgeration Cycle
%%%%%%%%%%%%%


% Compressor Points - Points 1 to 2 - Constant Entropy

S_Compressor = S_1; % Constant Entropy Process
P_Compressor_Summer = linspace(P_1,P_2_Summer,1000);
P_Compressor_Winter = linspace(P_1,P_2_Winter,1000);
T_Compressor_Summer = zeros(length(P_Compressor_Summer));
T_Compressor_Winter = zeros(length(P_Compressor_Summer));
S_Compressor_Summer = zeros(length(P_Compressor_Summer));
S_Compressor_Winter = zeros(length(P_Compressor_Summer));
H_Compressor_Summer = zeros(length(P_Compressor_Summer));
H_Compressor_Winter = zeros(length(P_Compressor_Summer));
for index = 1:1000
    T_Compressor_Summer(index) = CoolProp.PropsSI('T', 'P', P_Compressor_Summer(index), 'S',
S_Compressor, 'R410a') - 273;
    T_Compressor_Winter(index) = CoolProp.PropsSI('T', 'P', P_Compressor_Winter(index), 'S',
S_Compressor, 'R410a') - 273;
    S_Compressor_Summer(index) = CoolProp.PropsSI('S', 'P', P_Compressor_Summer(index), 'S',
S_Compressor, 'R410a');
    S_Compressor_Winter(index) = CoolProp.PropsSI('S', 'P', P_Compressor_Winter(index), 'S',
S_Compressor, 'R410a');
    H_Compressor_Summer(index) = CoolProp.PropsSI('H', 'P', P_Compressor_Summer(index), 'S',
S_Compressor, 'R410a');
    H_Compressor_Winter(index) = CoolProp.PropsSI('H', 'P', P_Compressor_Winter(index), 'S',
S_Compressor, 'R410a');
end
```

```
% Condensor - Points 2 to 2a - Constant Pressure

P_Condensor_Summer = P_2_Summer; % Constant Pressure Process
P_Condensor_Winter = P_2_Winter; % Constant Pressure Process
T_Condensor_Summer = linspace(T_2_Summer,T_2a_Summer+.25,1000); % Added constant .5 so it does not
go to the mixture
T_Condensor_Winter = linspace(T_2_Winter,T_2a_Winter+.25,1000); % Added constant .5 so it does not
go to the mixture
S_Condensor_Summer = zeros(length(P_Condensor_Summer));
S_Condensor_Winter = zeros(length(P_Condensor_Summer));
H_Condensor_Summer = zeros(length(P_Condensor_Summer));
H_Condensor_Winter = zeros(length(P_Condensor_Summer));
for index = 1:1000
    S_Condensor_Summer(index) = CoolProp.PropsSI('S', 'T', T_Condensor_Summer(index), 'P',
P_Condensor_Summer, 'R410a');
    S_Condensor_Winter(index) = CoolProp.PropsSI('S', 'T', T_Condensor_Winter(index), 'P',
P_Condensor_Winter, 'R410a');
    H_Condensor_Summer(index) = CoolProp.PropsSI('H', 'T', T_Condensor_Summer(index), 'P',
P_Condensor_Summer, 'R410a');
    H_Condensor_Winter(index) = CoolProp.PropsSI('H', 'T', T_Condensor_Winter(index), 'P',
P_Condensor_Winter, 'R410a');
end

% Condensor - Points 2a to 3 - Constant Pressure - Straight Line inside Vapor Dome

T_Condensora_Summer = [T_2a_Summer,T_3_Summer]; % Constant Temperature
T_Condensora_Winter = [T_2a_Winter,T_3_Winter]; % Constant Temperature
P_Condensora_Summer = [P_2a_Summer,P_3_Summer];
P_Condensora_Winter = [P_2a_Winter,P_3_Winter];
S_Condensora_Summer = [S_2a_Summer,S_3_Summer];
S_Condensora_Winter = [S_2a_Winter,S_3_Winter];
H_Condensora_Summer = [H_2a_Summer,H_3_Summer];
H_Condensora_Winter = [H_2a_Winter,H_3_Winter];




% Expansion Valve - Points 3 to 4 - Constant Enthalpy

H_Valve_Summer = H_3_Summer; % Constant Enthlpy Process
H_Valve_Winter = H_3_Winter; % Constant Enthlpy Process
P_Valve_Summer = linspace(P_3_Summer,P_4_Summer,1000); % Added constant .5 so it does not go to the
mixture
P_Valve_Winter = linspace(P_3_Winter,P_4_Winter,1000); % Added constant .5 so it does not go to the
mixture
S_Valve_Summer = zeros(length(P_Valve_Summer));
S_Valve_Winter = zeros(length(P_Valve_Summer));
T_Valve_Summer = zeros(length(P_Valve_Summer));
T_Valve_Winter = zeros(length(P_Valve_Summer));
for index = 1:1000
    S_Valve_Summer(index) = CoolProp.PropsSI('S', 'H', H_Valve_Summer, 'P', P_Valve_Summer(index),
'R410a');
```

```
    S_Valve_Winter(index) = CoolProp.PropsSI('S', 'H', H_Valve_Winter, 'P', P_Valve_Winter(index),
'R410a');
    T_Valve_Summer(index) = CoolProp.PropsSI('T', 'H', H_Valve_Summer, 'P', P_Valve_Summer(index),
'R410a');
    T_Valve_Winter(index) = CoolProp.PropsSI('T', 'H', H_Valve_Winter, 'P', P_Valve_Winter(index),
'R410a');
end



% Evaporator - Points 4 to 1 - Constant Temperature - Straight Line inside Vapor Dome

T_Evaporator_Summer = [T_4,T_1]; % Constant Temperature
T_Evaporator_Winter = [T_4,T_1]; % Constant Temperature
P_Evaporator_Summer = [P_4_Summer,P_1];
P_Evaporator_Winter = [P_4_Winter,P_1];
S_Evaporator_Summer = [S_4_Summer,S_1];
S_Evaporator_Winter = [S_4_Winter,S_1];
H_Evaporator_Summer = [H_4_Summer,H_1];
H_Evaporator_Winter = [H_4_Winter,H_1];


%%%%%%%%%%%%%
% Graphing the T-s and P-h Graphs with Vapor Dome and Labels
%%%%%%%%%%%%%

% T-s Graph for the Summer
figure(1)
% Vapor Dome
plot(S_SL/1000,T_SL,'k',S_SV/1000,T_SV,'k')
hold on
% Processes

% Winter
plot(S_Compressor_Winter/1000,T_Compressor_Winter,'b',S_Condensor_Winter/1000, T_Condensor_Winter-
273.15,'b',S_Condensora_Winter/1000, T_Condensora_Winter-
273.15,'b',S_Valve_Winter/1000,T_Valve_Winter-273.15,'b',S_Evaporator_Winter/1000,
T_Evaporator_Winter-273.15,'b')
text(S_1/1000,T_1-273.15, '\leftarrow State 1')
text(S_2_Winter/1000,T_2_Winter-273.15, '\leftarrow State 2')
text(S_2a_Winter/1000,T_2a_Winter-273.15, '\leftarrow State 2a','FontSize', 8)
text(S_3_Winter/1000-.04,T_3_Winter-273.15, 'State 3')
text(S_4_Winter/1000-.04,T_4-273.15, 'State 4')

% Summer
plot(S_Compressor_Summer/1000,T_Compressor_Summer,'r',S_Condensor_Summer/1000, T_Condensor_Summer-
273.15,'r',S_Condensora_Summer/1000, T_Condensora_Summer-
273.15,'r',S_Valve_Summer/1000,T_Valve_Summer-273.15,'r',S_Evaporator_Summer/1000,
T_Evaporator_Summer-273.15,'m')
plot(S_Compressor_Winter/1000,T_Compressor_Winter,'m') % plotting winter 1 to 2 for color
correction
text(S_1/1000,T_1-273.15, '\leftarrow State 1')
text(S_2_Summer/1000,T_2_Summer-273.15, '\leftarrow State 2')
text(S_2a_Summer/1000,T_2a_Summer-273.15, '\leftarrow State 2a')
text(S_3_Summer/1000-.04,T_3_Summer-273.15, 'State 3')
text(S_4_Summer/1000-.04,T_4-273.15-2, 'State 4')
```

```
text(1.3,40,'Cycle Starts at State 1 towards State 2','FontSize',16)

title('Refrigeration Cycle during the Summer in Durham, NH')
xlabel('Entropy (KJ/K)')
ylabel('Temperature (Celcius)')
xlim([.8 2])
ylim([-20 80])
hold off

% Syntax
title('Refridgeration Cycle during the Winter in Durham, NH','FontSize',20)
xlabel('Entropy (J/K)','FontSize',20)
ylabel('Temperature (Celcius)','FontSize',20)
lgd = legend('\color{red} Summer','\color{blue} Winter','\color{black} Vapor Dome');
lgd.FontSize = 20;
xlim([.8 2])
ylim([-20 80])
hold off





% P-h Graph for the Summer
figure(2)
% Vapor Dome
plot(H_SL/1000,P_SL_SV/1000,'k',H_SV/1000,P_SL_SV/1000,'k')
hold on
% Processes

%Winter
P_Condensor_Winter = [P_2_Winter,P_2a_Winter];
H_Condensor_Winter = [H_2_Winter,H_2a_Winter];
P_Valve_Winter = [P_3_Winter,P_4_Winter];
H_Valve_Winter = [H_3_Winter,H_4_Winter];
plot(H_Compressor_Winter/1000,P_Compressor_Winter/1000,'b',H_Condensor_Winter/1000,
P_Condensor_Winter/1000,'b',H_Condensora_Winter/1000,
P_Condensora_Winter/1000,'b',H_Valve_Winter/1000,P_Valve_Winter/1000,'b',H_Evaporator_Winter/1000,
P_Evaporator_Winter/1000,'b')
text(H_1/1000,P_1/1000, '\leftarrow State 1')
text(H_2_Winter/1000,P_2_Winter/1000, '\leftarrow State 2')
text(H_2a_Winter/1000-20,P_2a_Winter/1000-100, 'State 2a')
text(H_3_Winter/1000-20,P_3_Winter/1000, 'State 3')
text(H_4_Winter/1000-20,P_4_Winter/1000, 'State 4')

% Summer
P_Condensor_Summer = [P_2_Summer,P_2a_Summer];
H_Condensor_Summer = [H_2_Summer,H_2a_Summer];
P_Valve_Summer = [P_3_Summer,P_4_Summer];
H_Valve_Summer = [H_3_Summer,H_4_Summer];
plot(H_Compressor_Summer/1000,P_Compressor_Summer/1000,'r',H_Condensor_Summer/1000,
P_Condensor_Summer/1000,'r',H_Condensora_Summer/1000,
P_Condensora_Summer/1000,'r',H_Valve_Summer/1000,P_Valve_Summer/1000,'r',H_Evaporator_Summer/1000,
P_Evaporator_Summer/1000,'m')
plot(H_Compressor_Winter/1000,P_Compressor_Winter/1000,'m') % plotting winter 1 to 2 for color
correction
```

```
text(H_2_Summer/1000,P_2_Summer/1000, '\leftarrow State 2')
text(H_2a_Summer/1000-25,P_2a_Summer/1000-100, 'State 2a')
text(H_3_Summer/1000-20,P_3_Summer/1000, 'State 3')
text(H_4_Summer/1000-20,P_4_Summer/1000-50, 'State 4')
text(275,2500, 'Cycle Starts at State 1 towards State 2','FontSize',16)

% Plot Syntax
title('Refrigeration Cycle during the Summer and Winter in Durham, NH','FontSize',20)
xlabel('Enthalpy (KJ/K)','FontSize',20)
ylabel('Pressure (KPa)','FontSize',20)
lgd = legend('\color{red} Summer','\color{blue} Winter','\color{black} Vapor Dome');
lgd.FontSize = 20;
xlim([0 500])
ylim([0 5000])
hold off



%%%%%%%%%%%%%
% Calculating Flow-Rate Required, Compressor Power and Coefficient of Performance for Summer and
Winter Conditions
%%%%%%%%%%%%%


% Co-Efficient of Performance where COP = (QL/Wnet) = ((h1-h4)/(h2-h1))

COP_Summer = (H_1 - H_4_Summer)/(H_2_Summer - H_1);
COP_Winter = (H_1 - H_4_Winter)/(H_2_Winter - H_1);

% Mass Flow Rate where flow rate = Cooling Capacity / Q_L


dH_Evaporator_Summer = H_1 - H_4_Summer;
dH_Evaporator_Winter = H_1 - H_4_Winter;
Cooling_Capacity = 5000; % Watts
Mass_Flow_Rate_Summer = Cooling_Capacity / dH_Evaporator_Summer;
Mass_Flow_Rate_Winter = Cooling_Capacity / dH_Evaporator_Winter;


% Compressor Power

Compressor_Power_Summer = Mass_Flow_Rate_Summer * (H_2_Summer - H_1); % [J/s]
Compressor_Power_Winter = Mass_Flow_Rate_Winter * (H_2_Winter - H_1); % [J/s]



Final_Data_Names  = ['COP_Summer',' COP_Winter',' Mass_Flow_Rate_Summer',' Mass_Flow_Rate_Winter','
Compressor_Power_Summer',' Compressor_Power_Winter'];
Final_Data_Values =
[COP_Summer,COP_Winter,Mass_Flow_Rate_Summer,Mass_Flow_Rate_Winter,Compressor_Power_Summer,Compress
or_Power_Winter];


disp('Final Data'), disp(Final_Data_Names); disp(Final_Data_Values)
```

```
Final Data
```

```
COP_Summer COP_Winter Mass_Flow_Rate_Summer Mass_Flow_Rate_Winter Compressor_Power_Summer
Compressor_Power_Winter

   1.0e+03 *


    0.0048    0.0105    0.0000    0.0000    1.0369    0.4754
```