Water & Air Heat Pump Test

Analysis of Compressor and Evaporator Efficiencies of Water & Air with R134a

Submitted By

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Team #1

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Dear Mr. Sharma,

The report detailing the experiment performed and processed by Team #1 on 06/27/2023 is attached below. The team was tasked with collecting temperature data for various points along a heat pump circuit, in order to calculate and find the associated enthalpy & respective efficiencies for both water and air. The refrigerant R134a was used as the working fluid and therefore all enthalpies are derived from charts and tables for R134a thermodynamic properties.

Temperatures were checked by each team member for a total of 5 iterations for each respective cycle. Related values were then derived from tables/charts using the provided software for interpolation and used to calculate the coefficient of performance for both the condenser and evaporator for the water cycle. For the air cycle, it was only necessary to solve for the condenser efficiency. Only one series of temperature collections was used for data reduction, series 5 & 4 was used for water and air respectively. Using these series of raw data, thermodynamic values were extrapolated from charts and graphs and used to calculate the heat flux for the Water and Air heat pumps. It was found that both cycles produced strikingly close enthalpy-temperature charts and had similar heat flux ratios.

Sincerely,

Will Buziak, Dishan Desai, Bryson Hines

Seniors in Mechanical Engineering

Enclosed: Thin-Walled Pressure Vessel Test Report

Signed: ______________________________

Summary of Contributions:

Will Buziak (30%):

- Introduction
- Data Interrogation
- Data Reduction
- Conclusion
- What I learned

Dishan Desai (30%):

- Apparatus
- Data Reduction
- Conclusion
- What I learned

Bryson Hines (40%):

- Lists of Figures, Tables, and Symbols
- Procedure
- Data Reduction
- Conclusion
- What I learned

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List of Symbols

Symbol	Description	Units
COP_H	Coefficient of Performance in Heating	-
COP_C	Coefficient of Performance in Cooling	-
$\dot{m}_{ref}$	Mass Flow Rate of the Refrigerant	g/s
W_{in}	Power Input of the System	W
η	Compressor Efficiency	-
$W_{in_{actual}}$	Actual Rate of Work Input in the Compressor	W
C_p	Specific Heat	kJ/(kg-C)
h_1	Enthalpy at State 1	kJ/kg
h_2	Enthalpy at State 2	kJ/kg
h_3	Enthalpy at State 3	kJ/kg
h_4	Enthalpy at State 4	kJ/kg
ΔT	Change in Temperature	C
Q	Thermal Energy	kW

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Introduction

Objectives

The primary purpose of this experiment was to understand how working fluids interact with water and air to move heat against the natural heat flow. Other objectives include the ability to gather thermodynamic properties from charts or graphs and how they relate to one another. Learning the heat pump cycle and how it differs from other heat transfer cycles. Collecting data on a physical heat pump system allows the student to gain a more in-depth, comprehensive understanding of each state and how that affects the rest of the cycle. Understanding each state of the cycle is important to comprehend how heat exchangers work by manipulating the pressure, volume, and temperature of the working fluid to impact the output temperature.

Test Apparatus and Procedure

Apparatus

The primary apparatus used in this experiment was the Hylton Air and Water Heat Pump as seen in Figure 1. The components that make up the air and water pump are the evaporator, compressor, and condenser. The components are shown in Figures 2-4, respectively. In this experiment, the refrigerants that would be compared are water and air. The evaporator collects the refrigerant as a low temperature liquid and evaporates the liquid at a low pressure, so that it leaves a low temperature vapor. The heat pump obtains refrigerant data from the evaporator such as power, low and high pressure, flow rate, and the 4 temperatures at each state. These data are collected for both water and air, as they are collected from the water evaporator and air evaporator. The compressor raises the temperature and the pressure of the vapor that came from the evaporator. The condenser condenses the high temperature vapor into a high pressure and high temperature liquid. Once the refrigerant leaves the condenser, the refrigerant expands into a low temperature and low-pressure liquid. The refrigerant will return to the evaporator, and the cycle will repeat. The cycle is the same for both air and water.

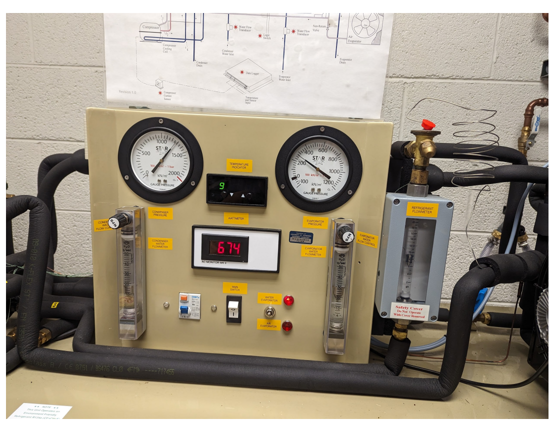

Figure 1. Air and Water Heat Pump

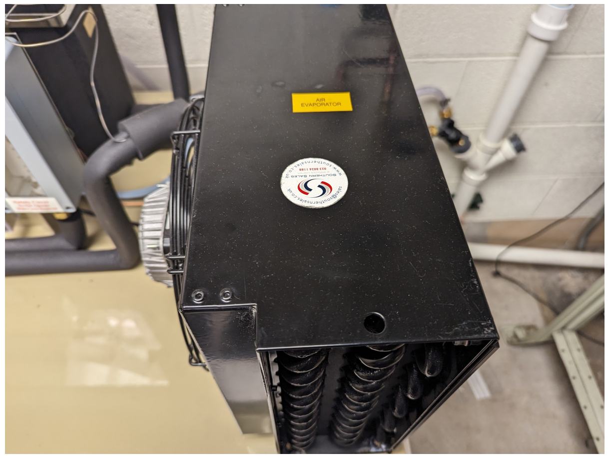

Figure 2. Air Evaporator

Figure 3: Compressor

Figure 4: Water Evaporator

Test Procedure

For this experiment, the testing apparatus shown in the above section was tested with both the water evaporator and the air evaporator setups. Firstly, team #1 was tasked to collect data with the water evaporator form of the heat pump system. Each student took turns gathering data required from the apparatus in five readings. On each reading, the student would first read the power from the AC monitor, of which the value is recorded in Watts. Then the student would record the low-pressure value and the high-pressure value, which could be read off of the gauges on the right and left side of the test apparatus respectively. Then the student would record the mass flow rate of refrigerant, which is recorded via the flow meter found on the right side of the apparatus. Then, using the digital readout, the student would record the data for temperatures 1-4. After collecting the data for the refrigerant, the student could collect the condenser water data. To do this the student would first read the mass flow rate of water in the condenser which can be read from the flow meter in the bottom left-hand corner of the apparatus. Then using the digital readout, the student could record the temperatures 6 and 7. Next the student could collect the evaporator water data. To do this the student would first read the mass flow rate of water in the condenser which can be read from the flow meter in the bottom right-hand corner of the apparatus. Then using the digital readout, the student could record the temperatures 8 and 9.

After all the data was collected for the water evaporator system, the data for the air evaporator system could be collected in a similar manner to that of the water evaporator system. First the heat pump had to be switched to the air evaporator using near the bottom of the apparatus. When the switch was flipped to the air evaporator, the air evaporator turned on and started to run. At this point the students waited five minutes for the temperatures to level out then proceeded with the following collection of data processes. Each student took turns gathering data required from the apparatus in five readings. On each reading, the student would first read the power from the AC monitor, of which the value is recorded in Watts. Then the student would record the low-pressure value and the high-pressure value, which could be read off of the gauges on the right and left side of the test apparatus respectively. Then the student would record the mass flow rate of refrigerant, which is recorded via the flow meter found on the right side of the apparatus. Then, using the digital readout, the student would record the data for temperatures 1-4. After collecting the data for the refrigerant, the student could collect the condenser water data. To do this the student would first read the mass flow rate of water in the condenser which can be read off of the flow meter in the bottom left-hand corner of the apparatus. Then using the digital readout, the student could record the temperatures 6 and 7. This then was all the collected data needed for the experiment.

Results and Discussion

Data Interrogation

The initial temperature change from T1 to T2 is expected to spike before decreasing slightly to T3 and then below T1 to T4. For each temperature collection, the data reflected this expectation for both the Water and Air evaporators. These expectations are based on the ideal thermodynamic cycle for a mechanical heat pump. This cycle includes any heat pump cycle that follows the basic processes based around the principle of adjusting the boiling point of a fluid by changing the pressure. Pressure values are read for both low and high pressure along with the flow rate and inlet/outlet temperatures. These temperatures are collected for reference in use with the tables for data reduction.

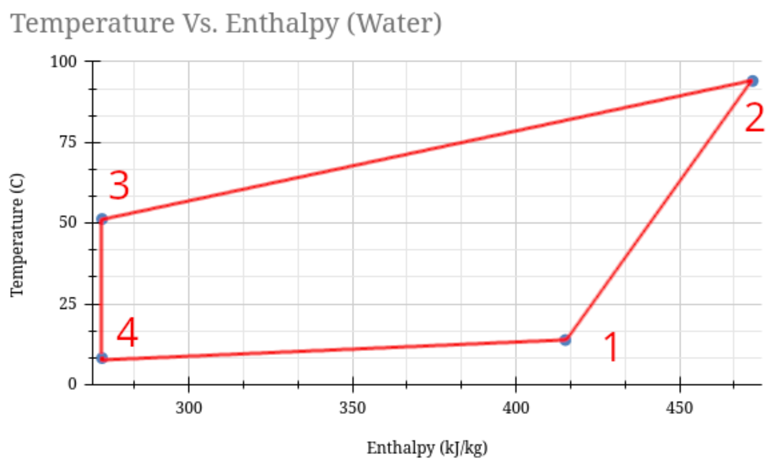

Figure 5: Temperature vs. Enthalpy (Water)

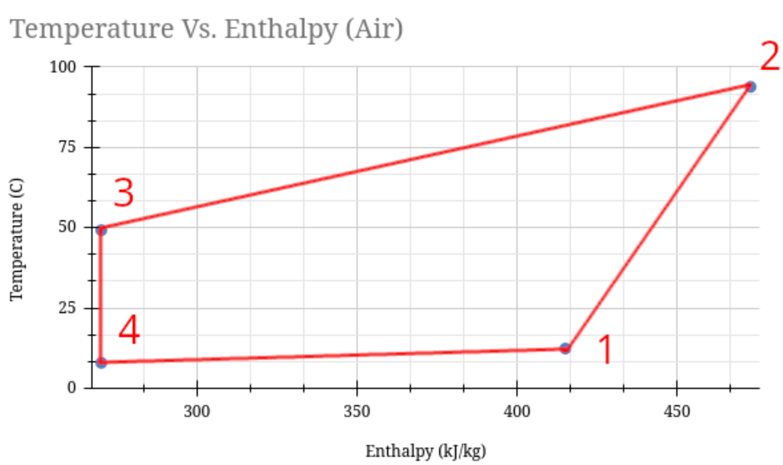

Figure 6: Temperature vs. Enthalpy (Air)

Figure 5 depicts the thermodynamic cycle as collected for the Water Evaporator when using the data from Reading No. 5. The same processes were repeated for the Air Evaporator utilizing the data from Reading No. 4 to compare, as shown in Figure 6. It can be noted that the respective cycles are strikingly close to each other in both Water and Air Evaporator scenarios. This behavior matches the expected behavior from an ideal refrigeration cycle. The collected state variables can be superimposed on another medium for finding each state's enthalpy values. The behavior displayed below in Figure 7 can be distinguished between Figures 5 & 6 for a variety of reasons.

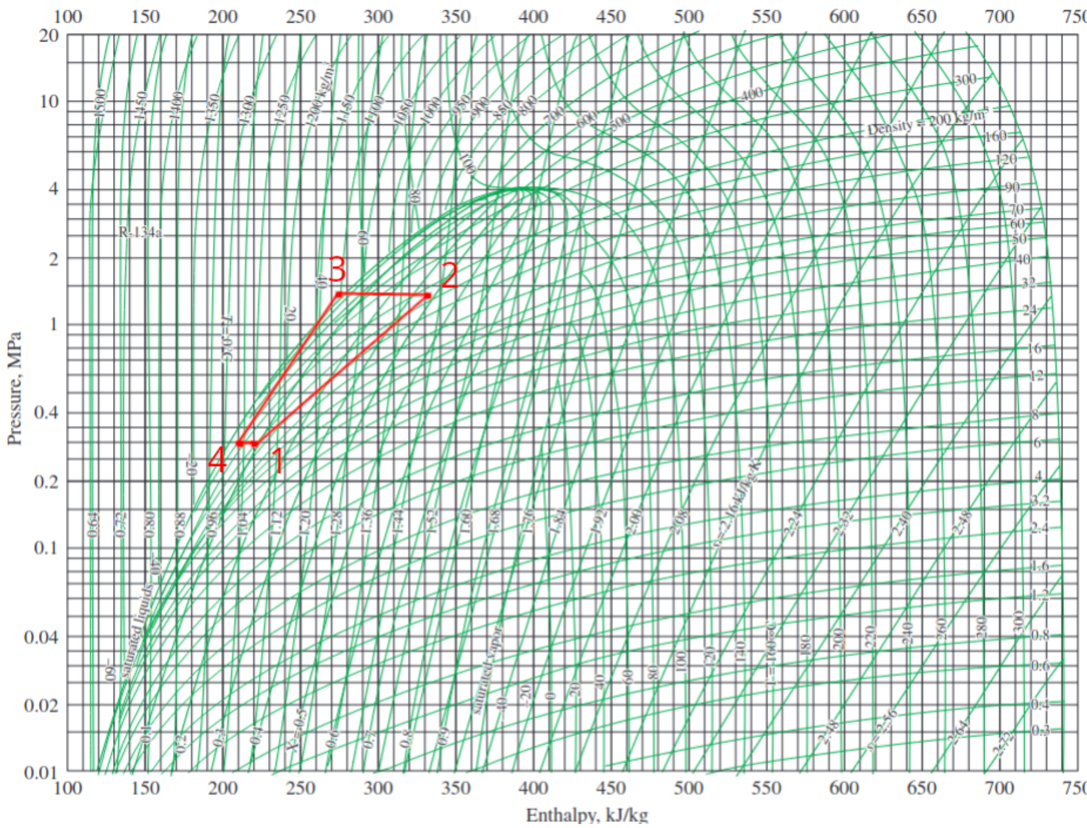

Figure 7: Pressure vs. Enthalpy Chart

It should be noted that Team #1 derived all values from provided software [1] to calculate all thermodynamic values for additional precision. Figure 7 is solely included for the purpose of providing another means of finding the specific enthalpy and when referencing another source for thermodynamic properties, the values can vary widely with respect to the former.

Data Reduction Procedure

The enthalpies, which are referred to as h1, h2, h3, and h4, were extracted from a software program provided from the class materials. [1] Additionally, the specific heat of water was found for both the condenser and evaporator. These values from known data are essential in the calculations of the Coefficient of Performance in Heating (COP_H)and Coefficient of Performance in Cooling (COP_C); the relevant equations used for data reduction were provided in the course material [2]. These said equations were used for data reduction and are shown below in equations 1 and 2.

$$COP_H = \frac{\dot{m_{ref}}[h_2 - h_3]}{W_{in}} \qquad [1]$$

$$COP_C = \frac{\dot{m_{ref}}[h_1 - h_4]}{W_{in}} \qquad [2]$$

The compressor efficiency of the heat pump can also be calculated once the enthalpies are extracted. The calculation for the compressor efficiency is seen on equation 3.

$$\eta = \frac{\dot{m_{ref}}[h_2 - h_1]}{W_{in}} \qquad [3]$$

It can be assumed that the compressor efficiency stays the same as it was for the "water evaporator" mode. As a result, the actual rate of work input in the compressor can be calculated with equation 4.

$$W_{in_{actual}} = \frac{\dot{m_{ref}}[h_2 - h_1]}{\eta_{water-mode}} \qquad [4]$$

The actual work input of the compressor from equation 4 is used to calculate the COP_H and COP_C of the air evaporator. The results of the two values will be similar compared to the COP_H and COP_C of the water evaporator.

The saturation temperatures were found with the associated high and low pressures to see if the state is superheated or subcooled. It was found that for states 1 and 2, the fluid was not superheated due to the collected temperatures being lower than the saturation temperatures at Phigh and Plow respectively. Additionally, the collected temperature for T3 was higher than the saturation temperatures at Phigh and is therefore not subcooled. The states can be determined as subcooled and superheated by comparing the collected temperature to its location respective to the saturated vapor line. This comparison represents the fluid's boiling point, if the measured temperature is higher or lower than the saturation temperature indicates if it is superheated or subcooled respectively [3]. Given that team #1 chose to utilize the provided software to calculate the thermodynamic state variables [1] the specific heat of water and all saturation temperatures were found with respect to the same source.

$$Q = \dot{m} C p \Delta T \qquad [5]$$

Utilizing the information measured and garnered from thermodynamic tables provides all necessary variables to calculate heat generated during the cycle. Heat can be calculated by the equation above, centered around the specific heat of water, mass flow rate & the change in temperature for the desired process. Heat generation was calculated for the water as well as both the hot and cold portions of the cycle for the working fluid.

Conclusions and Recommendations

In conclusion, this experiment demonstrated the differences in evaporator methods in a generic heat pump cycle. Using the given testing apparatus, the experiment was conducted to determine the difference between the enthalpy values of each heat pump cycle with their respective evaporators. The enthalpy results shown were as expected to follow a typical refrigeration cycle, however the compressor efficiency and coefficient of performance values were slightly different than normal refrigeration cycles levels. This could be due to a number of factors; however the collected data was consistent with other tests conducted on the same day so it is apparent that it could have been outside factors that contributed to the irregularities in the data.

An external factor that may contribute to the data collection is that there may be a possibility where the test apparatus did not reach a steady state prior to the initiation of the experiment. As a result, the recorded temperatures and pressure that were used to extract the enthalpies may not accurately represent the ideal testing conditions of the heat pump test. Consequently, the compressor efficiency was lower than the desired ratio of a typical heat pump. Braun provides further explanation of the compressor efficiency, "Typically, combined motor and compressor efficiencies are in the range of 0.4–0.8. Since a portion of the total compressor airflow is assumed to leak to the room at the compressor outlet and is replaced by make up air from the room at the drum outlet, the inlet condition to the compressor results from adiabatic mixing of air from the drum outlet and makeup air from the room." [4].

Improvement in the experiment includes using a newer model of the air & water heat pump, so that it takes less time for the pump to reach steady state when switching from the water evaporator to the air evaporator. For future experiments, it may be intriguing to test other refrigerants. The process to determine what refrigerant to test is explained by Chua, "In seeking for a potential replacement refrigerant, it is important to select one that has thermodynamic properties similar to the fluids being replaced. It should also possess the desirable attribute in terms of matching the enthalpy of vaporization." [5]. Utilizing other refrigerants may be necessary as they may have thermodynamics properties that can yield enthalpies that can ultimately improve compressor efficiency as well COP_H and COP_C .

What I Learned

I learned how pressure affects the boiling point of fluids and how that can be utilized in a thermodynamic cycle to push heat against the natural heat transfer gradient. As well as the differences between that of a water evaporator and an air evaporator and how each one of those has distinct characteristics that can affect the heat pump cycle. The change in this process also affects the enthalpy of various states of the heat pump cycle.

Editing Statement

"I Testify that I have read and edited this report before submitting it."

References

[1] Wischnewski, Berndt. "Calculation of thermodynamic state variables of tetrafluorethane - R134a" (2007) <http://www.peacesoftware.de/einigewerte/r134a_e.html>

[2] Majid Keyhani, "Course Document for Mechanical Engineering Laboratory (ME 449)", MABE Department, UT-Knoxville, January 2019.

[3] "Subcooling" (2023) <https://en.wikipedia.org/wiki/Subcooling>

[4] Braun, J.E. "Energy efficiency analysis of air cycle heat pump dryers" International Journal of Refrigeration (2001)

[5] Chua, K.J. "Advances in heat pump systems: A review" Applied Energy (2010): 3611-3624

[6] "What is Subcooling in an HVAC system?" (2023) <https://hvacprograms.net/subcooling/>

APPENDIX A: Original Test Data

Water & Air Heat Pump Test

June 27 2023

Will Buziak, Bryson Hines, Dishan Desai

Table 1: (Water Evaporator) Refrigerant Data

Reading No.	Power (W)	P_{low} (kPa, gauge)	P_{high} (kPa, gauge)	Flow Rate $\dot{m}_{ref}$ (g/s)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	Initials
1	676	275	1325	8	11.6	94.1	51.6	7.8	WB
2	677	275	1300	8	13.1	94.2	51.6	8.1	DD
3	673	275	1300	9	12.9	94.2	51.5	8.2	BH
4	682	275	1300	9	13	94.1	51.3	8.3	DD
5	**671**	**275**	**1275**	**9**	**13.8**	**94.1**	**51.3**	**8.3**	**BH**

Table 2: (Water Evaporator) Actual Pressures

P_{low} (kPa, total)	P_{high} (kPa, total)
376.325	1426.325
376.325	1401.325
376.325	1401.325
376.325	1401.325
376.325	**1376.325**

Table 3: (Water Evaporator) Condenser Water Data

Reading No.	Flow Rate $\dot{m}_w$ (g/s)	$T_6=T_{inlet}$ (°C)	$T_7=T_{outlet}$ (°C)
1	20	21.7	42.5
2	20	21.6	42.5
3	19	21.6	42.8
4	19	21.6	42.6
5	**20**	**21.7**	**42.6**

Table 4: (Water Evaporator) Evaporator Water Data

Reading No.	Flow Rate $\dot{m}_w$ (g/s)	T_8=T_{inlet} (°C)	T_9=T_{outlet} (°C)
1	32	21.4	12.6
2	31	21.4	12.1
3	32	21.4	12.4
4	32	21.4	12.3
5	**32**	**21.4**	**12.4**

Table 5: (Water Evaporator) Enthalpy Values

h_1 (kJ/kg)	h_2 (kJ/kg)	h_3 (kJ/kg)	h_4 (kJ/kg)
415	472.237	273.435	273.435

Table 6: (Water Evaporator) Saturation Properties

Saturation Properties			
Temp (°C)	Temp (°C)	Temp (°C)	h_f (kJ/kg)
7.05	51.68	51.68	274.3
			h_g (kJ/kg)
			424

Table 7: (Water Evaporator) Heat Values

Condenser		Evaporator	
c_p (kJ/kg-C)	4.183148797	c_p (kJ/kg-C)	4.18030348
Qw (kW)	1.748556197	Qw (kW)	1.203927402
Q_H (kW)	1.789218	Q_C (kW)	1.274085
Qw/Q_H	0.9772739807	Qw/Q_C	0.9449349158

Table 8: (Water Evaporator) Coefficients of Performance and Compressor Efficiency

Water Evaporator	
COP_H	2.666494784
COP_C	1.898785395
n	0.767709389

Table 9: (Air Evaporator) Refrigerant Data

Reading No.	Power (W)	P_{low} (kPa, gauge)	P_{high} (kPa, gauge)	Flow Rate $\dot{m}_{ref}$ (g/s)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	Initials
1	639	250	1225	8	12.6	93.4	49.8	8.3	WB
2	635	250	1250	8	13	93.9	49.3	8.3	BH
3	637	250	1225	8	12.2	93.9	49.2	7.9	DD
4	**631**	**250**	**1210**	8	**12.4**	**93.9**	**49.2**	**8**	**WB**
5	632	250	1200	8	12.6	94.1	49	8	BH

Table 10: (Air Evaporator) Actual Pressures

P_{low} (kPa, total)	P_{high} (kPa, total)
351.325	1326.325
351.325	1351.325
351.325	1326.325
351.325	**1311.325**
351.325	1301.325

Table 11: (Air Evaporator) Condenser Water Data

Reading No.	Flow Rate $\dot{m}_w$ (g/s)	$T_6=T_{in}$ (°C)	$T_7=T_{out}$ (°C)
1	19	21.6	41.3
2	19	21.6	41.3
3	19	21.6	41.3
4	**19**	**21.6**	**41**
5	19	21.6	41.1

Table 12: (Air Evaporator) Enthalpy Values

h_1 (kJ/kg)	h_2 (kJ/kg)	h_3 (kJ/kg)	h_4 (kJ/kg)
415.1	472.85	270.14	270.14

Table 13: (Air Evaporator) Saturation Properties

Saturation Properties			
Temp (°C)	**Temp (°C)**	**Temp (°C)**	**h_f (kJ/kg)**
5.128	49.792	49.792	271.3
			h_g (kJ/kg)
			423.3

Table 14: (Air Evaporator) Heat Values

Condenser		Evaporator	
c_p (kJ/kg-C)	4.183285523	-	-
Qw (kW)	1.541959044	-	-
Q_H (kW)	1.62168	Q_C (kW)	1.274085
Qw/Q_H	0.9508405134	-	-

Table 15: (Air Evaporator) Compressor Power

Power (Compressor) (W)
462

Table 16: (Air Evaporator) Coefficients of Performance

Air Evaporator	
COP_H	2.570015848
COP_C	1.837844691

APPENDIX B: Equipment List and Specifications

PV Test Equipment List

Name of Equipment	Model #	Serial #	Manufacturer	Purpose	Resol ution	Accuracy
Air Evaporator	PX302-500GV	N/A	SECOP		N/A	N/A
Air & Water Heat Pump	N/A	701908	P.A. Hilton Ltd.	Pump Refrigerant R134a	N/A	N/A
Water Evaporator	N/A	N/A	SECOP			N/A
Condenser	DP-350	N/A	SECOP			N/A
Fan	14V11	N/A	mavib	Push cold air pass the heat exchanger		N/A
Compressor	SC15G	N/A	SECOP	Compresses fluid Refrigerant R134a in order to lower the fluids volume	N/A	N/A
Transformer	E 4/5		Majestic Transformer Co.	Changes the voltage to run the system	N/A	N/A

APPENDIX C: Test Procedure

Water & Air Heat Pump Test

Procedure

Stage 1: Water Evaporator Test

This test begins by ensuring all equipment is properly connected and turned on. Ensure that the tap water is flowing from the provided spigot in the testing facility. Settings for water flow were preset to get rid of any bubbles in the refrigerant shown in the refrigerant flow meter. The apparatus should be set to the water evaporator setting using the labeled switch, and immediately afterwards the person conducting the experiment should wait 5 mins for the temperature values to level out. The steps to recording data are as follows, repeat these steps in order to collect and record the data 5 separate times on the provided Excel spreadsheet:

1. Collect temperatures T1 through T9 using the digital thermometer readout in the center face of the apparatus.
2. Collect the water flow rate data for both the condenser unit and evaporator unit using the flow meters to the bottom left and bottom right of the measurement apparatus respectively.
3. Collect the refrigerant flow rate data shown in the flow meter off to the right side of the apparatus.
4. Collect the refrigerant pressure data using the gauges located near the top face of the measurement apparatus.
5. Collect the power input data using the digital readout in the bottom center of the face of the measurement apparatus.

Stage 2: Air Evaporator Test

The apparatus should be set to the air evaporator setting using the labeled switch, and immediately afterwards the person conducting the experiment should wait 5 mins for the temperature values to level out. The steps to recording data are as follows, repeat these steps in order to collect and record the data 5 separate times on the provided Excel spreadsheet:

1. Collect temperatures T1 through T7 using the digital thermometer readout in the center face of the apparatus.
2. Collect the water flow rate data for the condenser unit using the flow meters to the bottom left of the measurement apparatus.
3. Collect the refrigerant flow rate data shown in the flow meter off to the right side of the apparatus.
4. Collect the refrigerant pressure data using the gauges located near the top face of the measurement apparatus.
5. Collect the power input data using the digital readout in the bottom center of the face of the measurement apparatus.

Stage 3: Clean Up

At this point, the person doing the experiment should turn off the testing apparatus using the power switch and then turn off the tap water flowing from the spigot in the testing facility. The test procedure is now complete, and data is ready to be processed.