MAE 4344 - Design Projects
HVAC Refrigeration Unit Final Report

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1.0 Introduction

1.1 Background

The HVAC refrigeration unit is an ongoing project for senior design students at Oklahoma State University under the provision of Dr. Ronald Delahoussaye and Dr. Christian Bach. A total of 4 senior design groups have worked on this project starting in January 2015 and ending with our group in spring of 2016. In August of 2015, the project became sponsored by ASHRAE with a $5,00 contribution. The university also sponsors this project with an additional $4,000. The purpose of this project was to create a refrigeration unit to be used for class demonstrations in undergraduate courses such as Thermodynamics, HVAC, and Heat Transfer. It will also be available for experimental use for graduate students.

In the spring of 2015, group 1 and 2 reviewed commercially available experimental set-ups, established the project direction, and purchased a small (5000 Btu/hr) air conditioning unit. These groups suggested that the primary components of the unit (i.e. the heat exchangers and compressor) be removed and integrated into a newly configured refrigeration system. More specifically, the refrigeration system would be organized onto a test stand that could be easily transported. Schematics of the design for the refrigeration system and test stand by group 1 can be seen in Figure A. 1 and Figure A. 2, respectively.

Group 3 began work on the project during the fall of 2015. Their work included the design and fabrication of the test stand, frame, and ductwork. They also mounted the compressor and heat exchangers from the 5000 Btu unit. Lastly, they purchased and installed the fans and pressure shutoff device. Figure 1 shows a picture of the system after group 3 was finished. Our group (group 4) was responsible for completing and finalizing this project in the spring semester of 2016.

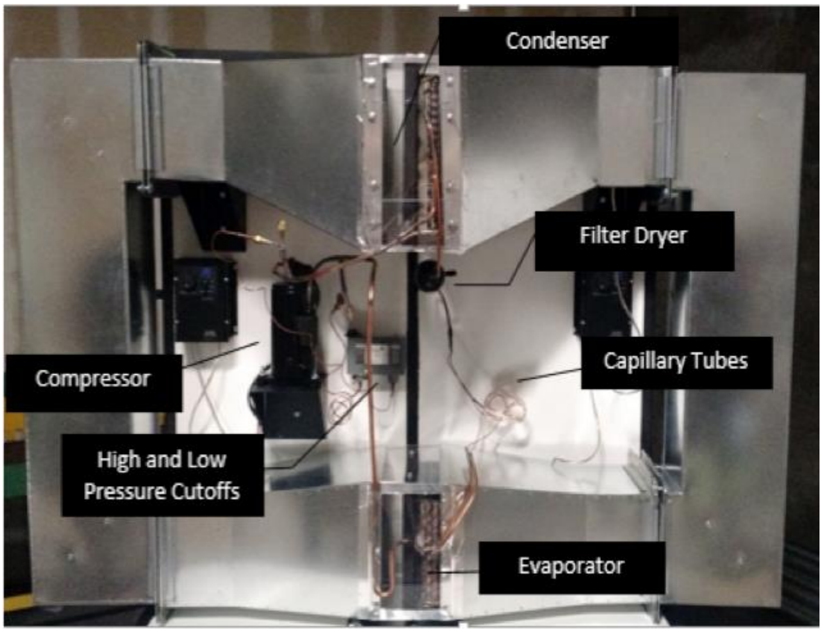


Figure 1: Group 3 Refrigeration Unit

1.2 Problem Statement

The material presented in university courses (specifically in Thermodynamics, Heat Transfer, and HVAC) is often taught in large classes in a purely theoretical manner that fails to incite the interest of some students. Professors may find it especially difficult to engage these students without access to a physical system that applies theory to real-life applications. Ultimately, this restricts students in their ability to exercise what they have learned in classes. As a solution, a senior design team has been assigned to an ongoing project that will be supplemental to classroom instruction and provide engineering students at Oklahoma State with a hands-on learning experience.

The aim of our project was to complete an HVAC refrigeration unit for in-class demonstrations. Students will be able to see measurements (temperature, pressure, enthalpy, and entropy) for different points in the system and also observe the different components on the unit during operation. Ultimately, we hope to achieve a fully operational refrigeration cycle that presents information in a clear and concise manner. We hope that our HVAC refrigeration unit provides a good learning experience for students in order to peak their interest in HVAC-related fields.

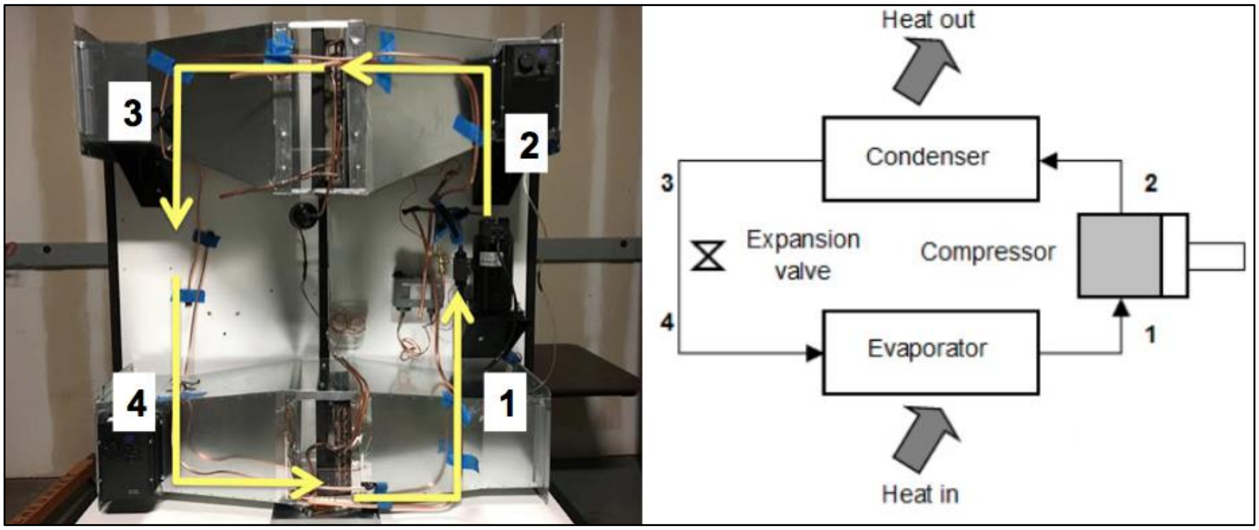
2.0 Deliverables

For this project we set out to accomplish the following:

- **Education**: students should walk away with a better understanding of a refrigeration cycle and an appreciation for HVAC systems as a whole.

- **Longevity**: the system should be able operate for a lifetime of 10 or more years (with yearly inspections).
- **Simplicity**: having the set-up organized in a way that is easy for students to understand
- **Safety:** all relevant safety issues will be considered and addressed. Measures will be taken to prevent any potential accidents.
- **Documentation**: operation manuals, reports, and other forms of documentation will be provided to ensure project organization.
- **Design**: decisions made for the system design should exhibit good engineering judgment. Additionally, all design requirements should be met.

We hoped to accomplish the items listed above by performing the tasks explained in the remainder of this section. At minimum, we wanted to have a finished, fully functioning refrigeration unit that could read and display temperatures and pressures of the refrigerant entering and leaving the compressor and expansion valve. This would require researching, purchasing, and installing appropriate instrumentation. We also promised to purchase a computer that would travel with the HVAC refrigeration unit. A data acquisition device (DAQ), as well as a LabVIEW program to read and display the temperatures and pressures measurements, would accompany the computer. To assist in safe, easy operation for future educators, we planned to create an instruction manual that would travel with the HVAC refrigeration unit as well. We also wanted to make the unit aesthetically pleasing and produce a simple design. One way this could be accomplished is by labeling the system components and use color-coding to indicate where heating and cooling occurs. We also wanted to rearrange the location of components on the unit to be consistent with the diagrams found in textbooks. See Figure 2 for our proposed layout and the corresponding system schematic. Another deliverable was a worksheet for in-class demonstrations. This worksheet would review students' knowledge of refrigeration cycles and allow them to work real-world example problems. Lastly, a LabVIEW program was necessary to output measurements from each point in the system to a monitor or screen. Any of the other deliverables for this project were contingent upon accomplishing the items already listed.



a.) Picture of set-up b.) Schematic

Figure 2: Schematic representation of our system

3.0 Final Design Overview

Overall, our refrigeration system operates as promised. The refrigerant travels across a series of piping through a compressor, condenser, expansion valve, and evaporator. Two variable-speed fans exist at the top right and bottom left corners of the set-up. These fans pass air through ductwork and across the condenser, to reject heat from the refrigerant, and the evaporator, to supply cold air to the room. As requested, instrumentation was purchased and installed onto our refrigeration unit. Instrumentation included pressure and temperature sensors, as well as manual pressure gauges. These were utilized in our system to take measurements at different points in the cycle. The sensors/gauges are located at the each corner of the test stand before and after each of the heat exchangers. The information from these components is ultimately used to calculate enthalpy and entropy and display their values on a screen via LabVIEW. A picture of our final product can be seen in Figure 3.

Figure 3: Final Set-up

4.0 Work Completed

4.1 Preliminary Work

Before working on the HVAC refrigeration unit, it was important for our team to brainstorm the activities required to solve the problem. Planning was essential to keep the project organized and meet the deadlines for each task. The first step was to review past documents from the previous teams and get "up-to-date" with the project. It was also very beneficial to meet with Dr. Bach and ask him questions. He helped us understand which tasks were most important and prioritize our work. We were then able to create a Gantt chart for the remainder of the semester, which can be found in Figure A. 3. Lastly, we needed to review the codes and standards relevant to our project, determine our equipment and facility requirements, and establish a budget. Once this preliminary work was completed, we were prepared to progress to the next phase of the project.

4.2 Selection of Instrumentation

One of the first tasks we wanted to complete was selecting the instrumentation and other equipment for our system. This includes: temperature and pressure gauges and sensors, expansion valve and controller, DAQ, compact computer (Intel Nuc) and mounting bracket, shutoff valve, sight glasses, tubing, and fittings. Instrumentation is mostly needed for the refrigerant side of our system, which is where the temperature and pressure measurements will be taken for our refrigeration cycle. The first few weeks of our project were spent researching all of these parts to determine which ones would perform the best on our HVAC refrigeration unit at the lowest cost. Our rationale for the selection of each part will be discussed below in detail.

We decided to use Resistance Temperature Detectors (RTD's) to measure temperature instead of powered circuits or thermocouples. RTD's are the most accurate method for temperature measurements and were also cheaper than thermocouples. They make use of a small amount of pure platinum that has a linear resistance change from 0°C to 100°C without calibration. These characteristics fulfilled our design requirements for temperature range and accuracy, making RTD's the most viable option. An image of our RTD's can be seen in Figure 3.

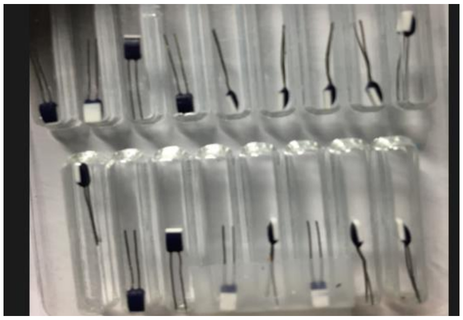


Figure 4: RTD's

For displaying pressure measurements, we decided to use Yellow Jacket manual pressure gauges (shown in Figure 4). These gauges are designed for our R410A refrigerant and were also suitable for the temperature and pressure ranges of the system. Additionally, they display both gauge pressure and saturation temperature. This particular model is also available in red and blue, which provides a visual representation for the high temperature and low temperatures sides of our system. The main use of these gauges is to compare values to those given by the transducers for accuracy. They also allow for easy viewing by students and those operating the unit.

Figure 5: Yellow Jacket manual pressure gauge

We looked at a number of models for pressure transducers. The main criterion was having an operating range of 0-250 psig for the low-pressure side and 0-500 psig for the high-pressure side. Other important criteria included accuracy and cost. Dr. Bach was able to locate the Setra pressure transducers, which offer the desired pressure range and were both cheaper and more accurate than other models. The pressure transducer we selected can be seen in Figure 5.

Figure 6: Setra Pressure Transducer

4.3 Selection of Other Equipment

A DAQ was required to process the data from the temperature and pressure sensors. An Instrunet iNet 550 model was chosen, shown in Figure 6. This DAQ also provided 28 channels, which exceeded the 20 or so that we required. Compared to other DAQ's with the same number of channels, the Intstrunet iNet 550 was the most reasonably priced. This model is also capable of reading voltage, current, and resistance without the need for additional equipment, which is very beneficial. It was very difficult finding a DAQ that fulfilled our specific requirements, which lead to some setbacks for our team. However, after a great deal of research and collaboration with Dr. Bach, we decided to spend a little more money on a DAQ that was able to fulfill all requirements. Ultimately, this high-end DAQ will provide more accurate readings with less of a chance for errors in the future.

Once the data is acquired, we needed a compact computer that was capable of running LabVIEW. We decided on the Intel Nuc (see Figure 7), which was relatively inexpensive and has all of the power and functionality that we need. It provides 3 USB ports, 2 HDMI inputs, an Ethernet input, and compatibility with LabVIEW. It is also small in size and takes up very little space when mounted inside of the cabinets.

Figure 7: Instrunet iNet 550 DAQ

Figure 8: Intel Nuc

To provide expansion in our system, as is custom in all refrigeration cycles, we also needed to order a device that could decrease the pressure of our system. Fortunately, personnel at Emerson were willing to donate an expansion valve of our choice. After reviewing their catalog, an EXM - BOA was chosen (seen in Figure 9) because it was an electronic expansion valve. This would give us the capability to control the mass flow rate through our LabVIEW program. The other option was an EXM-BOB model, which is essentially the same valve but slightly larger. We favored the BOA because an oversized expansion valve can cause a loss of precision in your calculations. As the motor is “stepping”, the steps to open and close the valve would be too large for the BOB model. On the other hand, the BOA model can take smaller, more precise steps.

Figure 9: Expansion Valve

The last piece of equipment that we needed was a controller for the expansion valve. We decided on the Arduino Uno, shown in Figure 8, which is equipped with a stepper motor shield. The purpose of this device is to control the mass flow rate through the valve. It is controlled via LabVIEW and can simply be connected to a computer with a USB cable. It features 14 digital input/output pins, 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, and a reset button. Everything considered, the Arduino Uno was the simplest option for controlling expansion.

Figure 10: Arduino Uno

Some other parts were required for the HVAC refrigeration unit, including: a computer monitor, mouse, HDMI cable, HDMI to VGA adapter, VGA cable, filter drier, and insulation for the RTD's. All of these items were purchased (and installed) as well, but further descriptions of their use are unnecessary.

4.4 LabVIEW

In order for the computer to be able to receive the pressure and temperature data from the DAQ and calculate other important values (enthalpy and entropy), a LabVIEW program was created. The program imports the pressure and temperature values from the DAQ and references thermodynamic properties of our refrigerant to establish the pressures, temperatures, enthalpies, qualities and entropies for the refrigeration cycle. To accomplish this, Steve was able to create a template from the LabVIEW adaptation of "ref prop", which computes unknown refrigerant properties based on two known refrigerant values.

Because phase changes of pure components occur at constant temperature and pressure, at points when the refrigerant is the mixture, knowing both of these properties is equivalent to knowing a single parameter. Therefore, some assumptions must be made about the system. Firstly, immediately after the compressor, the refrigerant is assumed to be superheated. This means that refrigerant is completely gas, and knowing temperature and pressure is sufficient information to calculate the other refrigerant properties. Secondly, after the condenser, the refrigerant is a mixture; therefore, another property, aside from temperature and pressure, must be known to fix the state of the refrigerant. It can be assumed that the quality at this point is 0 i.e. pure liquid. Knowing the quality and the pressure, we can calculate the enthalpy and entropy of the system at this point. Next, the refrigerant goes through an expansion valve and is still a mixture. The quality of the system cannot be assumed to be anything at this point; however, the expansion can be assumed to be isenthalpic. This means that if we take the enthalpy before the expansion and pair that with the measured pressure or temperature after the expansion we can determine the refrigerants state at this point as well. Finally, the refrigerant passes through the evaporator. Once again the refrigerant is a mixture and knowing the temperature and pressure is only half of the information that is needed to ascertain the state of the refrigerant. The final assumption we make is that the refrigerant has a quality of one, i.e. completely gas. With the quality and pressure or temperature, the state of the refrigerant can be determined.

In short, temperature and pressure are used to set the point after the compressor. Pressure is enough to set the point after condensing with a quality of 0 (saturated liquid). The enthalpy from after the condenser is used to find the mixed phase that occurs after expansion. Finally pressure and a quality of 1 (saturated vapor) are used to set the state before the compressor.

Figure 11 shows the interface that will be used to output pressure, temperature, enthalpy, quality and entropy data to students for all 4 points in the refrigeration cycle. Figure 12 shows the back panel of LabVIEW.

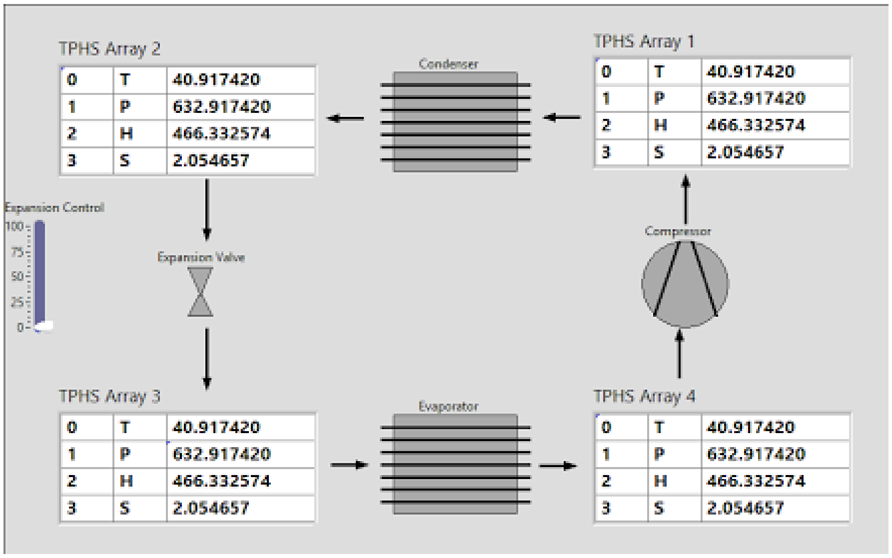


Figure 11: LabVIEW interface

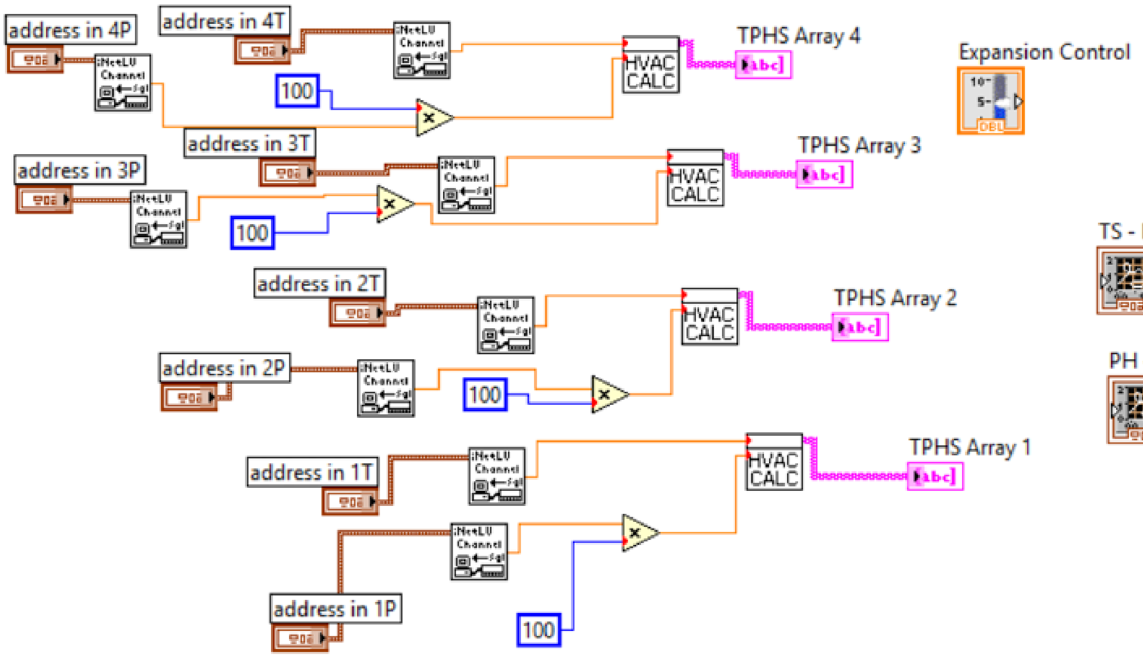


Figure 12: LabVIEW back panel

4.5 Outsourcing the System and Additional Tasks

To make the HVAC refrigeration unit operational, it was necessary to outsource all instrumentation to personnel at Meridian Technology Center who were certified to work with refrigerant. However, all instrumentation could not be ordered and received in the expected time frame. This was due do several setbacks such as receiving wrong parts, certification requirements for certain purchases, and a few other complications. While waiting on all the instrumentation to be received, our team used this downtime to accomplish a few other tasks. One of these tasks was creating a rough draft for a student worksheet that will be used during class demonstrations (see Figure A. 4). This worksheet will introduce our system and its purpose and then ask the students a series of questions in lab format based on their observations of the system. In order to improve aesthetics, we also rearranged the refrigerant side of our set-up. Our team met one afternoon to implement these changes by moving the fan controllers in front of their respective fans, moving the compressor and pressure cutoffs to the right side of the set-up, and shaping the piping to form a square. The changes made at that meeting can be seen in Figure 9.

Upon receiving all instrumentation, we labeled all fittings, instrumentation, and flare nuts to ensure that everything would be installed properly. Next, we delivered the unit to Meridian Technology Center where new piping was installed, instrumentation was connected to the piping via fittings, and the system was charged with refrigerant. During the installation process, Meridian discovered a leak in our evaporator. However, they were able to seal the leak and run the system again with no loss of pressure. Additionally, 2 of the pressure transducers were placed in the wrong position during the installation process. The 0-250 psig transducer was placed after the compressor while the 0-500 psig transducer was placed before the compressor. Once this mistake was pointed out, the team at Meridian Technology Center was able to quickly resolve the issue. At that point, our system was fully operational and we were able to transport the unit back to campus.

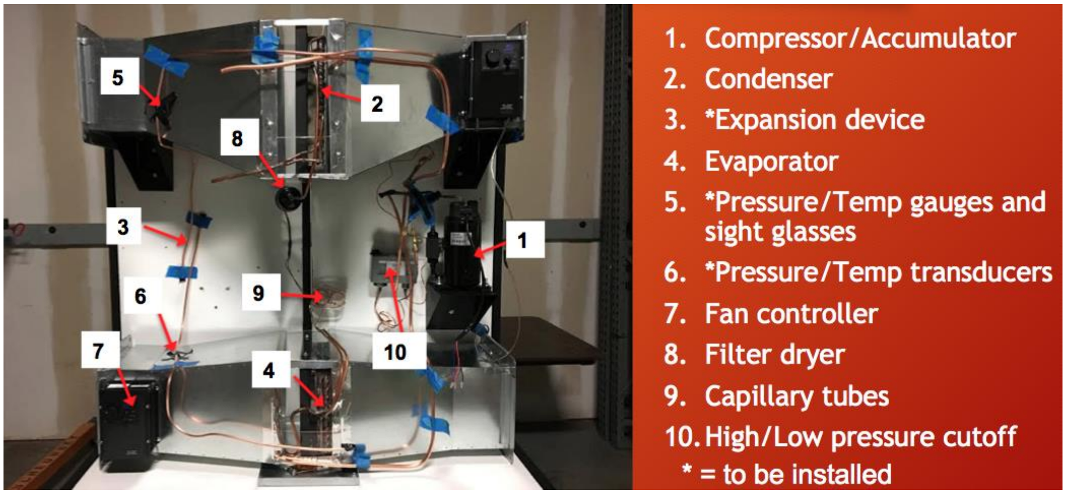


Figure 13: System layout after updates

4.6 Finalizing the System

Once we retrieved the system from Meridian Technology Center, we had to wire components, install sensors, and test the output values to LabVIEW. After testing our compressor, Mr. Snowden at Meridian Technology Center suggested purchasing a 35 microfarad capacitor to run it. Our first task was to install the capacitor and wire it up to the compressor. Because our leads of the compressor were fairly short, we needed to mount the capacitor close to the compressor. With the assistance of Dr. Conner, we were able to 3D print a holder for the capacitor that could be mounted to the test stand with screws. When wiring to the compressor, mistakes were made in the wire colors of insulation type and grounding. Dr. Bach was able to find someone to advise us in how to safely wire 120 AC current to our compressor. He also assisted in grounding all of the metal surfaces to prevent shorts from causing potential injuries to students.

After working with the capacitor, we had to wire and attach the RTDs to the system. Wire was soldered onto the leads of the RTDs. Heat shrink and electrical tape were used to help prevent shorts. After the wires were connected and insulated, the tubing was cleaned using Scotch Brite (to remove any oxide) and cotton balls with rubbing alcohol (to remove the particulate matter). The RTDs were attached to the tubing first with rubber bands, then with Arctic Alumina, a thermal epoxy. This ensured the sensors would have a low thermal resistance between them and the refrigerant. To complete the setup, insulation was used to cover the RTDs so their temperature will be nearly the same as that of the tubing. Finally, holes were drilled into the stand and all wires were run along the back side of the system into a hole leading to the cabinets. This helped remove clutter from the front of the system. When then attached the temperature and pressure sensors to the DAQ and began testing values.

4.7 Other Experiences

While our unit was a Meridian Technology Center, a local ASHRAE meeting was held at Oklahoma State University on April 6th. At this meeting, our team presented our project to the group of local HVAC engineers. In our presentation, we described the work completed and explained the benefits of creating an HVAC refrigeration unit for class demonstrations. In addition to our presentation to ASHRAE, we also participated in the Industrial Advisory Board poster presentations. Several representatives from different companies were present and asked us questions about our unit. Both of these presentations were great opportunities for our team to be exposed to the HVAC industry and interact with other more experienced engineers.

5.0 Final Design

5.1 Detailed Description

A schematic of the complete layout for the refrigerant side of our system can be seen in Figure 10. The refrigerant, R410A, travels through a compressor, condenser, expansion valve, and evaporator. Each of these components have an affect the quality, temperature, and pressure of the fluid. Measurements are taken via temperature sensors (RTDs) and pressure sensors (pressure transducers). The sensors/gauges are located before and after the compression and expansion processes. This allows us to determine the state of the system at each of the 4 critical points. A DAQ measures the voltages provided by our sensors, converts the voltage to a measurement, and sends the information to LabVIEW where other properties are calculated. Airflow across the heat exchangers is controlled by two variable-speed fans at opposite corners of the set-up. These fans pass the air through ductwork and across the heat exchangers. A low/high pressure shutoff is used to prevent over/under pressurization of the high and low sides, respectively. This is vital for our system because it will prevent the compressor from running when our expansion valve is in the closed position. A 35 microfarad capacitor is used to shift the phase of the incoming ac power to allow the compressor to run. Manual pressure gauges are also installed so the system pressures can easily be checked even when unpowered. Sight glasses provide students with a way to see the phase at each of the 4 states. They were also used when filling up the system to supply the correct charge. An inline filter drier in the refrigerant system removes water and other contaminants that might be in the system. Additionally, an accumulator is located before the compressor to prevent excess liquid from entering the compressor. Our system was laid out in a rectangular configuration that resemble the schematic commonly used in textbooks. It also helps the system align with a T-s or P-V diagram.

Overall, inputs to the HVAC refrigeration unit are: amount of expansion (controlled in LabVIEW) and the fan speed (controlled manually by the dial on the fan controllers). The function of the system is generally the same regardless of these inputs, but different fan speeds or amounts of expansion result in different thermodynamic properties at each of the 4 locations. In practical terms, our HVAC unit is used to cool the air going into a space much like an air conditioner. The evaporator allows for heat to be rejected from the refrigeration side of our system to the air. Similarly, the condenser cools the air being passed across it. This air is passed into the conditioned space, much like the air being diffused into building zones during summer months.

E.1	Thermocouples
E.2	Pressure Transducers
E.3	Low Pressure Cutoff
E.4	High Pressure Cutoff
E.5	Fans (Air Side)

R.1	Compressor
R.2	Accumulator
R.3	Condenser
R.4	Evaporator

M.1	Sight Glasses
M.2	Filter Dryer
M.3	Electronic Expansion Valve
M.6	Mechanical Pressure Sensors

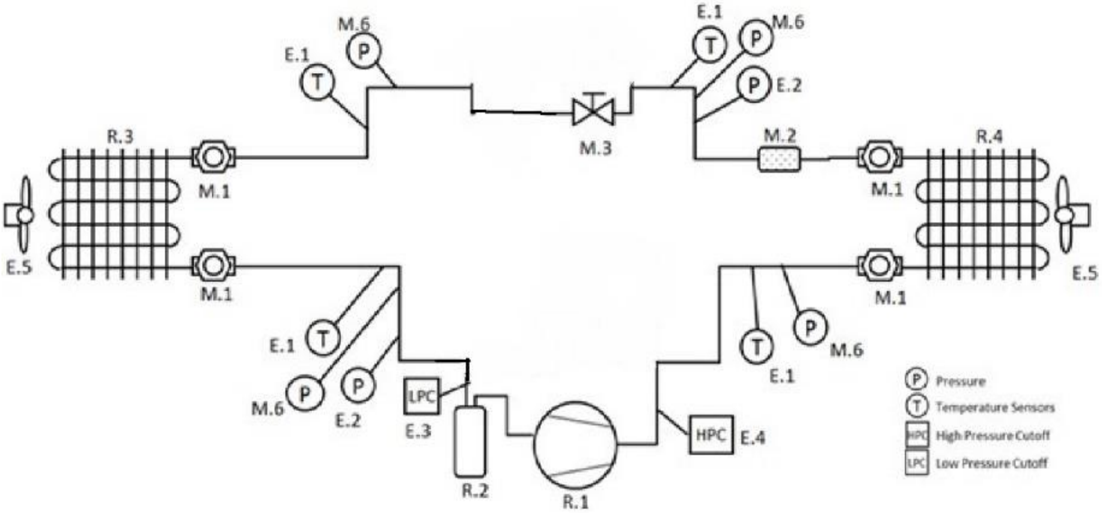


Figure 14: Refrigerant-side schematic

5.2 Evaluation

By the end of the semester, our group hoped to have a fully operational refrigeration system. We accomplished the goal and now have a running refrigeration unit that displays measured values via LabVIEW. However, there are a few initial goals that we not seen to completion. This includes: air-side instrumentation, self generating T-S and P-V plots, controlling the expansion valve with LabVIEW, mounting a monitor to the test stand, a finalized student worksheet, and component labels. Our main errors were delays in communication and miss prioritising components. These two factors caused our shut-off valve to be one of the last parts we purchased. This in turn delayed the soldering of the system by Meridian and prevented us from working on these additional points sooner. With careful planning and execution, the system could have been assembled earlier. This would have given the team time with the complete test stand to check the computer systems and add additional sensors for the airside.

However, we believe that we delivered a system that satisfy the primary requirements and will provide students with a good learning experience.

6.0 Recommendations for Future Work

Future groups could add to this project by installing airside instrumentation, performing maintenance, and supportive documentation. Air side instrumentation includes but is not limited to: wet bulb temperature, dry bulb temperature, and air fow measurements. This would allow the system to be used for instruction in HVAC, thermal systems, and heat transfer courses. Maintenance will also need to be conducted in the future. Both the evaporator and condenser are exposed to unfiltered air. As the system is operated dust will accumulate, reducing the efficiency of these components. Installing and changing an air filter or cleaning the fins every 2-4 years should be sufficient to help prevent this from being a serious problem. Corrosion will be an issue with this system because the cold side condenses water. Additionally, corrosion could be caused by electric potential from temperature differences. Any contact between the tubing and the duct work will also result in corrosion. The copper tubing vibrates a fair amount, this could lead to leaks developing in the system as the copper fatigues. If these leaks become excessive, the heat exchangers will likely need to be replaced. This leads to the next point, which is additional supports and mounting components. Struts connecting the copper tubing to the ductwork would significantly reduce vibrations in the system, increasing it's life. Care will have to be taken with the material used and the connection to the copper to prevent corrosion. The nook and DAQ are currently not mounted to the stand. This could result in damage when the stand is moved.

The LabVIEW program also needs to be controlled by the electronic expansion valve (stepper motor) via an arduino interface in the form of a subVI. The subVI was provided by Dr. Bach. The front panel has two slides and a byte controller that can control the number of steps the expansion valve takes, or the speed at which the steps are taken, or resets the expansion to fully closed. The LabVIEW program also needs to contain a T-S plot for students to see. This will be done by averaging different values between points, i.e. between states 3 and 4, during the evaporator, the pressure will be held constant and the quality will be changed over a few steps from the quality at state 3 to state 4. A separate LabVIEW front panel could also be created for airside demonstrations. This LabVIEW work will be done by Stephen Powers over the next few weeks to get the front panel to where it needs to be for student understanding.

7.0 Budget Overview

This project was allotting a total budget of $9,000, including a $5,000 sponsorship from ASHRAE and an additional $4,000 from Oklahoma State University. The previous groups before us spent a total of $4000, leaving us with $5000 to spend. Our remaining budget at the end of the semester was $865. Each of the purchases made was documented in an Excel sheet. This can be in Figure 15.

Part - Name	Supplier	# of parts	Cost/part	Total Cost	Shipping
DAQ - Inet - 555, Inet - 430, Inet - 510	Omega	1	$ 1,565.00	$ 1,565.00	
DAQ to LabView - INET - 380	Omega	1	$ 195.00	$ 195.00	$ 10.00
Pressure Transducer (500 psi) - 2061500PG	Setra	2	$ 215.84	$ 431.68	$ 25.21
Pressure Transducer (250 psi) - 2061500PG	Setra	2	$ 204.34	$ 408.68	
Temperature Sensor - PPG102A1	Mouser	21	$ 5.60	$ 117.60	$ 6.99
Mechanical Pressure Gauge HP - T9FB461205	Global Industrial	2	$ 19.24	$ 38.48	
Mechanical Pressure Gauge LP - T9FB461206	Global Industrial	2	$ 17.25	$ 34.50	$ 12.78
Shut-off Valve - SS-DSS4 - 1/4"	Swagelok	1	59.18	59.18	
Sight Glass - 6AWU3 - 3/8"	Grainger	4	$ 26.10	$ 104.40	$ 16.31
Sight Glass - 6AWU2 - 1/4"	Grainger	2	$ 32.90	$ 65.80	$ 7.72
Arduino Uno R3 - Product #50	Adafruit	1	$ 24.95	$ 24.95	
Arduino Motor Shield - Product #1438	Adafruit	1	$ 19.95	$ 19.95	$ 7.34
USB Cable - Standard A-B (3 ft/1m)	Adafruit	1	$ 3.95	$ 3.95	
Computer - Intel Nuc	Amazon	1	$ 429.00	$ 429.00	$ 5.49
Nuc Mounting Bracket	Amazon	1	$ 29.95	$ 29.95	$ 8.87
Expansion Valve - EXM - B0A	Emerson	1	$ -	$ -	
Fitting - Full Flare tee 1/4"	Supply House	6	$ 2.10	$ 12.60	
Fitting - Full Flare tee 3/8"	Supply House	4	$ 3.05	$ 12.20	
Fitting - 1/4" Brass Female Flare Swivel	Supply House	4	$ 2.25	$ 9.00	
Fitting - 3/8" Brass Female Flare Swivel	Supply House	4	$ 3.60	$ 14.40	
Fitting - 1/4" Flare X 1/4" FIP	Supply House	2	$ 0.97	$ 1.94	
Fitting - 1/4" Flare X 1/8" FIP	Supply House	2	$ 1.13	$ 2.26	
Fitting - 3/8" Flare X 1/4" FIP	Supply House	2	$ 1.08	$ 2.16	
Fitting - 3/8" Flare X 1/8" FIP	Supply House	2	$ 2.20	$ 4.40	$ 6.95
Shielded Cables - 22 Gauge	ProWire and Cable	30	0.56	16.8	11.46
Pipe Insulation - 1/4" - R = 4	Grainger	1	11.56	11.56	
Pipe Insulation - 3/8" - R = 4	Grainger	1	12.98	12.98	
Monitor - Asus - 21.5"	Amazon	1	109.99	109.99	0
Monitor Wall Mount	Amazon	1	99.99	99.99	0
HDMI to VGA Converter	Amazon	1	10.99	10.99	0
Local Purchases			SubTotal	$ 3,849.39	$119.12
3/8" OD x 50 ' Refrig Tube	Locke Supply Co.	1	33.5	33.5	
1/4" OD x 50' Refrig Tube	Locke Supply Co.	1	33.5	33.5	
3/8" Heavy Short Flare Nut	Locke Supply Co.	8	0.97	7.76	
1/4" Heavy Short Flare Nut	Locke Supply Co.	12	0.97	11.64	
Keyboard	Best Buy	1	$ 29.99	$ 29.99	
Mouse	Best Buy	1	$ 19.99	$ 19.99	
Filter Dryer (L3097)	Locke Supply Co.	1	$ 30.00	$ 30.00	
			Sub Total	$ 166.38	
			Total	$ 4,015.77	
			Available?	$ 5,000.00	
			Net	$ 984.23	

Figure 15: Budget

Appendix

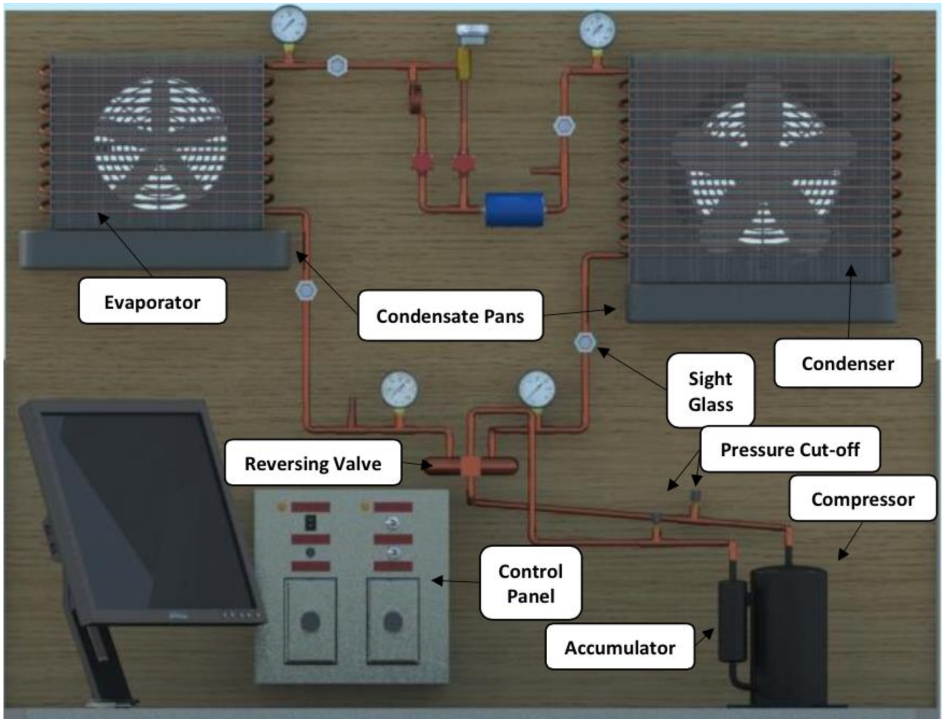


Figure A. 1: Proposed system layout from group 1

ACTIVITY	START	DURATION	PERCENT COMPLETE
PROPOSAL	1	4	
Project Introduction	1	4	100%
PROGRESS REPORT	5	5	
Order in-line instrumentation and Computer	5	2	0%
Install instruments, rework piping , charge refrigerant	6	2	0%
Make device operational	8	2	0%
CLOSEOUT	10	16	
Display thermodynamic properties via labview	10	3	0%
Labels, color-coding, etc. to improve functionality	11	2	0%
Examine device for safety & design flaws	12	1	0%
Close-out documentation and operational manual	13	2	0%
Demonstrate in a meeting or classroom setting	14	1	0%

Figure A. 3: Original Gantt Chart

Figure A. 4: Student Worksheet Draft

Refrigeration System Experiment *(DRAFT)*

Purpose

Thermodynamics are typically taught in a very dry manner, lacking hands-on experiments to ignite student interest necessary for effective learning. For that very reason, many students view thermodynamic as a nuisance rather than as the useful tool that it actually is. That in turn leads to graduates with a lack of experience and knowledge in basic thermodynamics as well as in advanced ASHRAE related fields such as psychrometrics and heat transfer. This is not desirable for our local building and environmental systems research group as well as for ASHRAE and the HVAC&R industry in general. Therefore we see the urgent need to reintroduce experiments into undergraduate and graduate thermal sciences classes.

The unit in front of you will run a refrigeration cycle. While it is in use, you will have the opportunity to see a physical system that applies the theory you have learned in classes to a real-life application. Since some of you have only being exposed to the theory of a refrigeration cycle, a real life system might seem a bit confusing a first. The following questions will help you acquire a better understand of the different components of the system and understanding of refrigeration as a whole.

Questions

1. Identify the major components in the system (i.e. the compressor, evaporator, condenser and expansion device). Where is each located on the set-up?

2. From your knowledge of heat transfer, what is a more general name we could assign to the condenser and evaporator? What are they used for? **Ans: Heat Exchanger. To increase heat transfer and heat/cool the refrigerant.**

2. Draw a schematic for a refrigeration cycle as it would appear in a textbook. Mark the 4 points for each of the stages and label them, starting with 1 after the evaporator.

3. Show the refrigeration process on a T-s diagram, labeling each point.

4. In a real world application, what would be the purpose of system such as this one?

5. This system uses a program called *LabVIEW* that is run on a computer. *LabVIEW* interprets pressure and temperature data from the DAQ (data acquisition) device, which is then displayed on a monitor or projector. Once the refrigeration cycle begins, fill in the following table:

Stage	Pressure [unit]	Temperature [Unit]
1		
2		
3		
4		

*Remember, stage 1 begins after the evaporator

6. Observe the “sight glasses” that have been inserted into the copper piping. What do you notice about the phase of the refrigerant during each stage? What do we know about temperature and pressure for 2-phase or “saturated” refrigerant?

7. From the information gathered in questions 5 and 6, determine the purpose for each component in the system. In other words, what happens to the temperature and pressure? Is there a phase change? Are there multiple phases present?

Other topics for potential questions:
- understanding differences between refrigerant vs air side
- safety
- current events (name some of the organization that apply HVAC concepts – ASHRAE, etc)
- Example problem from Thermo 2 notes
- Comparing hand calcs to output

Figure A. 5: Instruction Manual

HVAC Demonstration Unit Start-up Guide

**BEWARE OF HIGH VOLTAGE. The capacitor (in the plastic container behind the compressor) has high voltage going across the top. Don't touch this capacitor while the system is running!*

1. Plug in the white power cord sticking out of the lower backside of the system. The computer, monitor and DAQ are all plugged into this power strip, so this is the only cord needs to be connected to an outlet.
2. Open up the bottom cabinets and press the power button on the Nuc (Small black computer with cords sticking out of it).
3. If you wish to view the data on the monitor then you don't have to do anything, it is already set up for the monitor. But if you wish to use a projector or some other device to view our LabVIEW interface, simply unplug the HDMI cord from the back of the computer monitor and plug it into the monitor of your choosing. If you are using a projector , a VGA adapter and VGA cord are included. Use these to connect the Nuc to the projector.
4. Once you have a visual on your monitor/projector, you can flip the switch in the middle of the system to start up the compressor. Note: it might take a few minutes to start up because the capacitor has to charge. Next, flip the switches on the fans and set the speed by turning to dial on the controllers. Use high speeds for best results.
5. Now using the wireless mouse and keyboard that are in the bottom compartment, open up LabVIEW by clicking on the yellow-triangle icon that is pinned to the taskbar on the right side of the screen. (It is right below the Google Chrome icon)
6. Once LabVIEW appears, open up the file called "Open Instrunet 2.vi". It should be on the right side of the page under the tab called "Open Existing." Once it is open, select Network Page from the drop down menu and run the Vi. It will appear to open up the DAQ software separately but it is running in LabVIEW.

7. Next you need to go to the window that the Vi opened up and click open in the top left corner, selecting the "Refrigeration Setup" file that is located on the desktop.
8. Finally, you can go back to LabVIEW and open up the file called "Senior Design." It is located in a file called "HVAC Demo Setup" on the desktop.
9. Once it is open, you can go to the front panel and scroll down to the boxes labeled "Refrigerant RTD Inputs" and "Refrigerant Pressure Inputs". A couple of these numbers will need to be changed before you can get reading on the LabVIEW interface. The "network" and "device" sections on all of them do not need to be changed, but the "module" setting on all 8 needs to be changed to 2. Your monitor or projector should now be able to display real-time temperature, pressure, enthalpy, and entropy values.

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