

MAE 4344-Design Projects
HVAC Group

HVAC Demonstration Unit Design Final Report

Final Report prepared by:
Kellie Backhaus (Team Leader)
Kourtney Backhaus

Advisor:
Christian K. Bach

Due Date: July 29th, 2016
Date Submitted: July 27th, 2016

1 Introduction

1.1 Background

The heating, ventilation, and air conditioning (HVAC) demonstration unit has been a continuous senior design project for 5 student teams. The overall goal of this project was to create a demonstration unit for students to use during class. During phase 1, two senior design teams developed designs for a HVAC demonstration unit, resulting in two reconfigurable units. Figures 1 and 2 show the two setups developed during phase 1. During phase 2 of the project, one team consisting of three students re-assessed the previous team's reports, combined the two existing designs, fixed design flaws, and built the unit. The steel frame was built as shown in Figure 3. During phase 3 the setup was completed, but lacks an expansion valve controller, software functionality, airside instrumentation, and required documentation for class use.

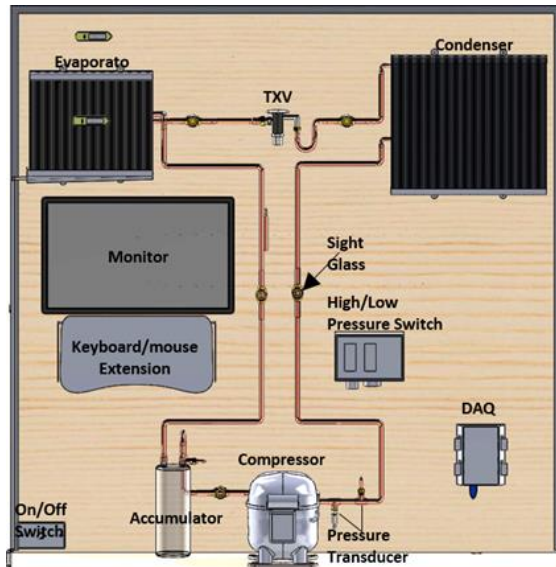


Figure 1: First phase 1 design [1]

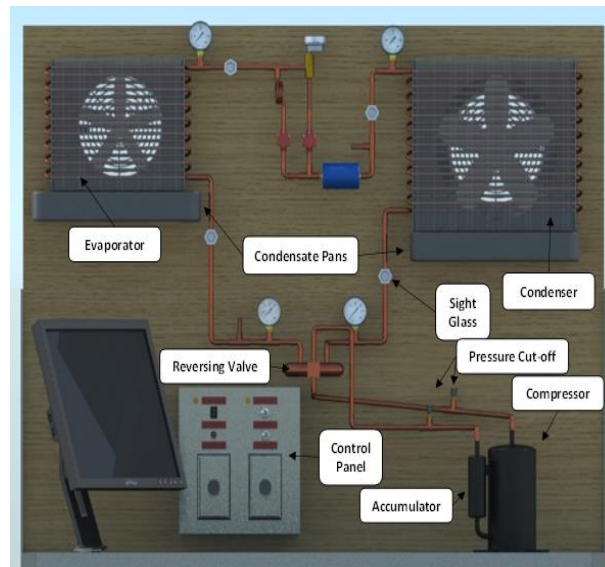


Figure 2: Second phase 1 design [2]

1.2 Problem Statement

Thermodynamics is a very complex field of study, because of this it is often overlooked by students. The goal of this senior design project was to complete a HVAC unit that will give future students the opportunity to have hands-on experience, instead of a theoretical only experience in class. We wanted to create a real-life experience so that students can see how cycles work in thermodynamics. The students will be able to measure temperature and pressure instead of just drawing diagrams for these cycles. This project is a step forward in getting students involved, as well as interested in the diverse field of thermodynamics.

Figure 4 shows where the phase 3 group finished and where our group began. Our group was responsible for finalizing the existing HVAC demonstration unit. This included completing data acquisition, correcting previous design flaws, and documenting all procedures. We worked to complete the unit so that it can be implemented to use in classroom settings. We want future students to be able to begin using the HVAC unit as a learning tool.



Figure 3: Phase 2 build [3]



Figure 4: Phase 3 setup

2 Deliverables

- Software functionality

Making sure the data is recording properly, as well as in a manner that is easy for students to understand when working with the unit.

- Airside instrumentation

Implementing humidity and temperature sensors into the airside portion of the unit.

- Documentation

Documenting all necessary procedures to follow while using the unit, as well as maintenance procedures.

- Cosmetic updates

Ensuring the unit is sturdy and easy to move so that it will last for 10 years.

- Student education

Helping the students walk away with a better understanding of thermodynamic cycles by including hands-on experience.

Our goal was to complete the deliverables listed above in order to create a fully functioning unit that is ready to be used in class settings. We needed to implement updates to the unit in order to create a learning tool for future students. We planned to begin this by updating the software functionality. We wanted to create Temperature - Entropy (T-s) and Pressure - Enthalpy (P-h) diagrams so the students could see how each state operates. We hoped to accomplish implementing airside instrumentation so that the unit was recording values of both air and refrigerant. We needed to update and complete the manual for operation in order to make sure the students had step by step procedures for using the unit. Maintenance documentation was also necessary to complete in order to ensure that the unit will run for ten years. We also promised to make cosmetic updates to the previous design. This included securing the copper tubing, mounting the monitor, and adding handles to assist in moving the unit. Finally, we wanted to ensure that students can get the most out of the unit.

3 Final Design

Our final design completes basic data acquisition by displaying the previously installed sensors data accurately, as well as providing future students a way to plot the data. As requested, airside instrumentation was purchased and installed onto the unit. This included temperature and humidity sensors. We also completed updates to the unit in order to make it easier to move to and from classrooms, as well as ensure the unit is secure. We completed the necessary documentation needed for the unit to be ready for in class use, and to provide the students with guidelines while working with the unit. Figure 5 shows our completed project.



Figure 5: Final design

4 Work Completed

4.1 Airside Instrumentation Selection

We needed three humidity sensors to calculate the airside capacity. Two of the sensors were going to be used for the inlet humidity to both coils, and then one for the exit humidity from the evaporator coil. We chose to use relative humidity sensors so that we could just use one sensor that combines both relative humidity and temperature. The sensor accuracy for sensors measuring relative humidity “must be within ± 5 percent relative humidity over the range of 20 percent to 80 percent” [4]. We compared three sensors in order to choose the sensor that best fit our application and the required specifications. A brief comparison can be seen in Table 1.

Table 1: Sensor comparison table

| Specifications | HIH-4021-002 | Setra Model SRH | HIH-4030 |
|--|--------------|---------------------|-------------|
| Ouput | Analog | Analog | Analog |
| Max Operating Supply Voltage (V) | 5.8 | 10 | 5.8 |
| Min Operating Supply Voltage (V) | 4 | 0 | 4 |
| Accuracy | $\pm 3.5\%$ | $\pm 2\%, 3\%, 5\%$ | $\pm 3.5\%$ |
| Relative Humidity Range | 0-100% | 0-100% | 0-99% |
| Max Operating Temperature ($^{\circ}\text{C}$) | 85 | 60 | 85 |
| Min Operating Temperature ($^{\circ}\text{C}$) | -40 | -40 | -40 |
| Price | \$17.53 | \$76.00 | \$16.95 |

The first two sensors we looked at were the Honeywell HIH-4021-002, shown in Figure 6, and the Setra model SRH. The Honeywell HIH-4021-002 fits the accuracy needed for our unit, and is cheaper than the Setra model SRH. The Setra model SRH has multiple selections for choosing different levels of accuracy, this makes the SRH able to obtain better accuracy [5]. However, the price also increases as accuracy increases. The SRH also has smaller limits when measuring operating temperature as compared to the HIH-4021-002.



Figure 6: Honeywell HIH-4021-002 [6]

We planned to purchase the HIH-4021-002, because it was cheaper than the Setra model SRH and met our required specifications. However, this sensor was back ordered and was not going to arrive in time, so we had to choose a different option. We then compared the Honeywell model HIH-4030, shown in Figure 7, with the first two sensors. This sensor had very similar specifications to the HIH-4021-002 and would arrive in time. The HIH-4030 also met the requirements needed for our humidity sensors. Since we were working with a restricted budget and could get the three HIH-4030 sensors that we needed for less than one Setra model SRH, we chose to purchase the Honeywell HIH-4030.



Figure 7: Honeywell HIH-4030 [7]

We also needed to select and purchase temperature sensors to complete the airside instrumentation for the unit. The sensors the previous group purchased are the US sensor PPG102A1, shown in Figure 8. We planned to order more temperature sensors, but we found extra sensors that the previous group did not use. Before deciding to use the US sensor PPG102A1 we wanted to do some research on them. The previous group chose resistance temperature detectors, (RTD's) because they are less expensive than thermocouples and more accurate. RTD's measure change in resistance in order to determine temperature, but thermocouples do not. RTD's are generally made of platinum, nickel, or copper. These materials are much better at predicting the change in resistance due to temperature, therefore making them much more accurate. This sensor has a platinum element with glass coating, as well as nickel lead wires. This sensor also has a linear relationship between temperature and resistance, recording up to 1kOhm. Since the previous group ordered the temperature sensors in bulk we were able to use their extras in order to reduce cost.



Figure 8: US sensor PPG102A1 [8]

4.2 Data Acquisition (DAQ) Software Development

Our first priority with data acquisition was to find a way to display data accurately. When we first began working with the unit it was unable to run. However, we did verify that the installed sensors were accurately reading room temperature values. The sensors are wired to the DAQ and then are displayed in a program called InstruNET, shown in Figure 9.

| Channel | Hdwr | N# | D# | M# | Ch# | Value Input | Units | % sRate | Sensor |
|-----------|------|----|----|----|-----|-------------|-------|---------|---------|
| Ch1 Vin+ | i430 | 1 | 1 | 2 | 1 | 23.6381 | C | 100 | RTD |
| Ch3 Vin+ | " | 1 | 1 | 2 | 3 | 23.026 | " | " | " |
| Ch5 Vin+ | " | 1 | 1 | 2 | 5 | 26.1299 | " | " | " |
| Ch7 Vin+ | " | 1 | 1 | 2 | 7 | 23.7605 | " | " | " |
| Ch9 Vin+ | " | 1 | 1 | 2 | 9 | +2.158 009 | Volts | " | Voltage |
| Ch11 Vin+ | " | 1 | 1 | 2 | 11 | +2.158 009 | " | " | " |

Figure 9: Measured values from sensors in InstruNET

InstruNET then sends this data to LabVIEW where the data is displayed while the unit is running. The user interface for LabVIEW that the students will use can be seen in Figure 10. The values in LabVIEW were also displaying temperature values at room temperature before the unit was running. However, once the unit was running the values were updating in InstruNET which meant that the sensors were accurately reading data, but LabVIEW was not.

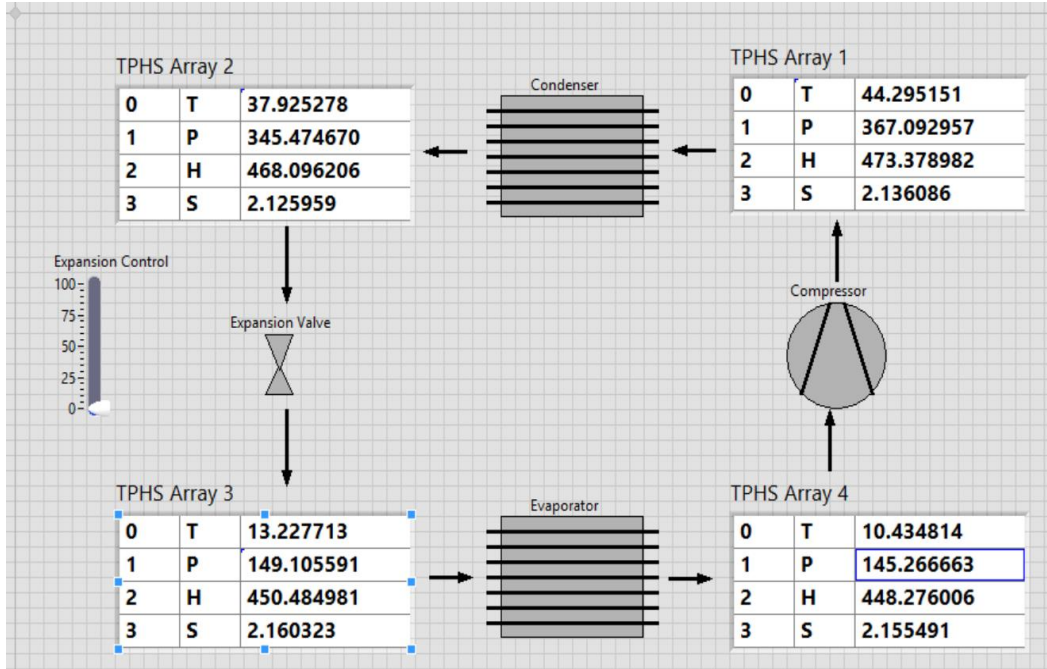


Figure 10: LabVIEW user interface [2]

While troubleshooting with LabVIEW we discovered that the channels were not accurately set. All four of the temperature sensors and the pressure transducers were set to

read values from the same channel, meaning the same sensor. Once we realized this was creating the problem, we were able to update LabVIEW so that each sensor would display its' appropriate data. We also set the values to default so that the problem will not occur again. Once the correct pressure and temperature values are in LabVIEW, a program called Refprop will calculate the entropy and enthalpy values and display them in LabVIEW.

Our next task with data acquisition was to complete T-s and P-h diagrams. We were able to complete this by using Refprop. When first trying to open Refprop we received an error message. After troubleshooting this as well, we were able to fix the problem so that the Refprop application could be accessed. In addition, we provided documentation with the procedures we used in order to fix this problem if it occurs in the future.

In order to create a T-s diagram as shown in Figure 11, the data from LabVIEW must be exported to Refprop. Once created, the plots can then be saved or copied to a program such as Microsoft Word. The students can then add state points as well as cycles to their diagrams for additional practice.

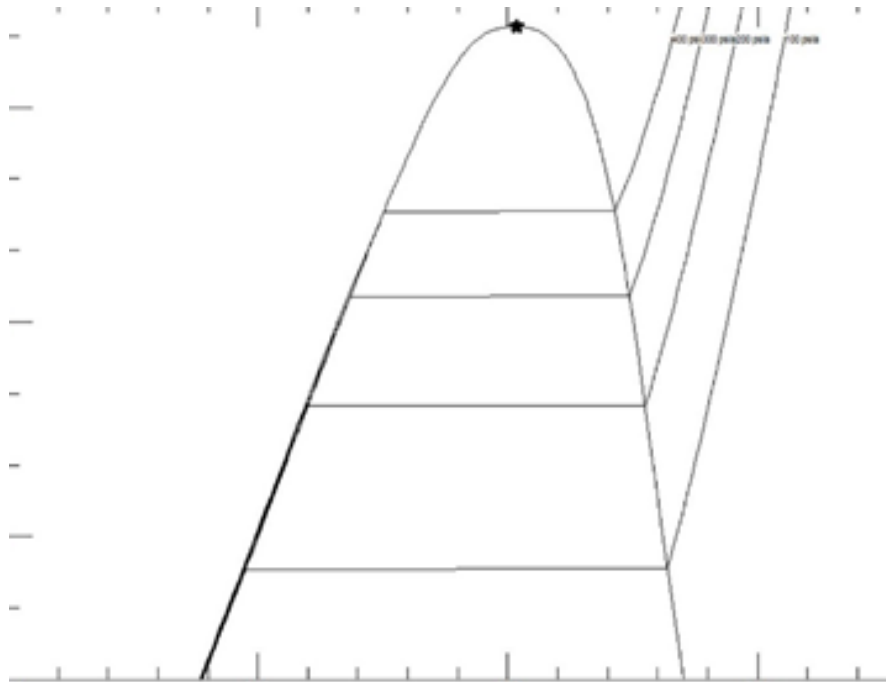


Figure 11: T-s diagram in Refprop

4.3 Additional Equipment Selection

In order to complete the cosmetic updates, we had to select equipment that would update the previous design flaws. Our first priority was to attach a handle to the unit in order to make it easier to move around. After looking at pre made carts, we decided that 39 inches was

a good height for the handle. We were originally going to use a plastic pre made handle. A sketch of the design is shown in Figure 12. As you can see in the figure, the handle was going to be at a height of 28 inches. This was much shorter than our goal height of 39 inches. However, the handle could not be raised any higher because the ductwork had to be attached. We were also afraid the pre made handle would not be sturdy enough.

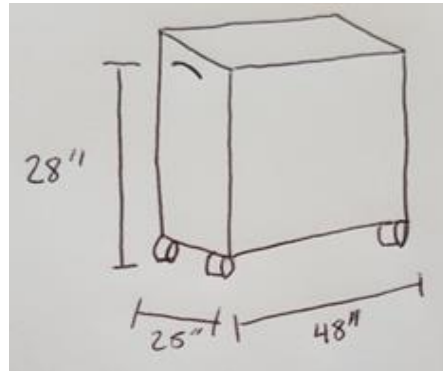


Figure 12: Plastic pre-made handle

Our next idea was to use steel tubing to make a handle. After brainstorming different ideas for where and how to attach the steel handle, we came up with a plan. Figure 13 shows a sketch of our idea. We planned to purchase two 18 inch long pieces of steel tubing to attach at either end of the unit. The handles would be at a height of 42 inches which was above our goal height of 39 inches. These handles would allow the user to either push or pull the unit. They would also be easy to grab and hold while moving the unit. Since they are steel tubes, they would also be sturdy enough to move the unit.

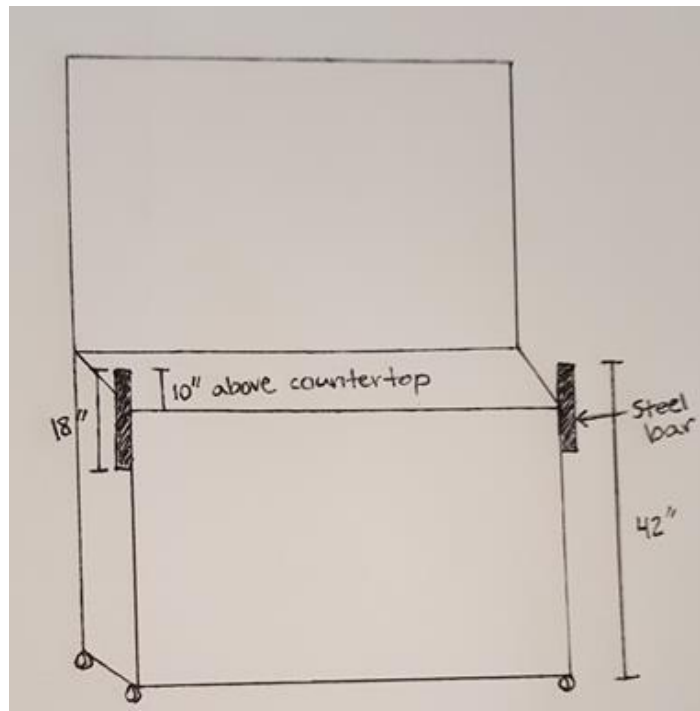


Figure 13: Steel tube handle

The next cosmetic update we needed to complete was securing the copper tubing. This was crucial in order to prevent the copper tubes from becoming fatigued and breaking or starting to leak. We chose to use truss ties, shown in Figure 14. These would help support the weight of the copper tubes as well as provide support when moving the unit. We chose to use these because they should support the copper well, and they would blend in with the ductwork. We hoped to find something that would support the copper, while also being discrete.



Figure 14: Copper tubing support [9]

We chose to purchase a wire organizer to put under the unit. This would be used for storing important documents, as well as minimizing clutter underneath the unit. This would provide the unit with a designated place for all documents in order to ensure that they stay with the unit when it is moved to and from classrooms. We initially chose to purchase command strips to mount the power strip underneath the unit. This would have allowed the power strip to be moved easily if necessary. However, after further consideration we decided that command strips might not be able to hold the power strip because of the weight of the cords, so we chose to use screws instead. In order to add to the student's experience, we decided to add magnetic component labels for the students to use when working with the unit. These magnetic labels would give the students a chance to test their knowledge by labeling each component in the cycle before beginning to work with the unit.

4.4 Documentation

It is important to ensure that future students know the steps in order to operate the unit. We have updated the startup guide created by the previous group in order to have the most accurate instructions. These instructions start by telling the students how to turn the unit on, as well as tell them how to collect and plot the data. The previous group also created an example experiment for the students to use. Our group created an answer key for the experiment for

students to use to check their work. In addition, we added a list of helpful steps and instructions in order to fix the channel problems with the DAQ if it arises again. Our group also created and received approval on the standard operating procedure for the unit. This document provides the steps for operating the unit as well as any safety concerns and how to deal with them. The Mechanical and Aerospace Engineering Safety Board approved our project to be used for future class use. We also created a maintenance document in order to make sure the unit is maintained so that it will last for 10 years. We provided documentation for all of the maintenance we have completed, as well as suggestions for future maintenance. This documentation includes steps on how to seal the sight glasses in case future leaks occur.

4.5 Updated Codes and Standards

We have reviewed many relevant codes and standards for our project. Table 2 shows the specific codes we used. We made sure that the fan cover openings complied with the standards. OSHA 1910.212(a)(5)[13] says that the maximum fan cover opening size is ½ inch. Our fan cover openings are ½ inch, which complied with this standard. We used ASHRAE 90.1 to verify that the sensor we chose met the specifications.

Table 2: Relevant codes and standards

| Code/Standard | Description |
|------------------------------|---|
| ANSI/ASHRAE 37 - 2009 [10] | Methods of testing for HVAC equipment |
| ANSI/ASHRAE 41.1 - 2013 [11] | Standard method for temperature measurement |
| ASHRAE 41.2 - 1987 [12] | Methods for measuring laboratory airflow |
| OSHA 1910.212(a)(5) [13] | Standard opening sizes for fan covers |
| ISO 13857 [14] | Safety of Machinery |
| ASHRAE 90.1-2013 [4] | Energy standard for buildings except low-rise residential buildings |

We also calculated the minimum safety distance required between the fan and fan cover using ISO 13857. Our fan cover has a maximum square opening of 12.7 mm (0.5 inches), which is between the range of 11 and 16 mm. The appropriate minimum safety distance for this range is between 48 and 66 mm. We interpolated using 12.7 mm in order to find the minimum safety distance required. We calculated a distance of 54.1 mm, which equals 2.13 inches. After measuring the actual fan cover, it is 2.25 inches from the fan blades. $2.25 > 2.13$ inches, therefore it exceeds the minimum safety distance and did not need to be changed.

4.6 Airside Instrumentation Installation

We installed 3 humidity sensors, as well as 2 temperature sensors on the unit. We installed the humidity sensors first by drilling a hole in the back of the ductwork. We did this so

the cables would be more discrete. After feeding the cables through the holes, we soldered the wires together to connect the sensors. We then mounted a truss tie inside the ductwork in order to secure the sensors in place. We placed the sensors in the middle of the airflow, shown in Figure 15, so that they would collect the most accurate data. We followed this same procedure for all 3 of the humidity sensors. The only difference for the sensor in the top ductwork is that it is not mounted to a truss tie. The hole was drilled in the top of the ductwork and the sensor was fed down to the appropriate place. We were not able to mount this one because we had no way of getting into the ductwork to mount a truss tie. It was important that we did not mount the humidity sensors at the condenser and evaporator exit too close to the coils. The sensors needed to be far enough away to prevent water droplets from hitting the sensors. Solid state humidity sensors can lose calibration if they become saturated [15].

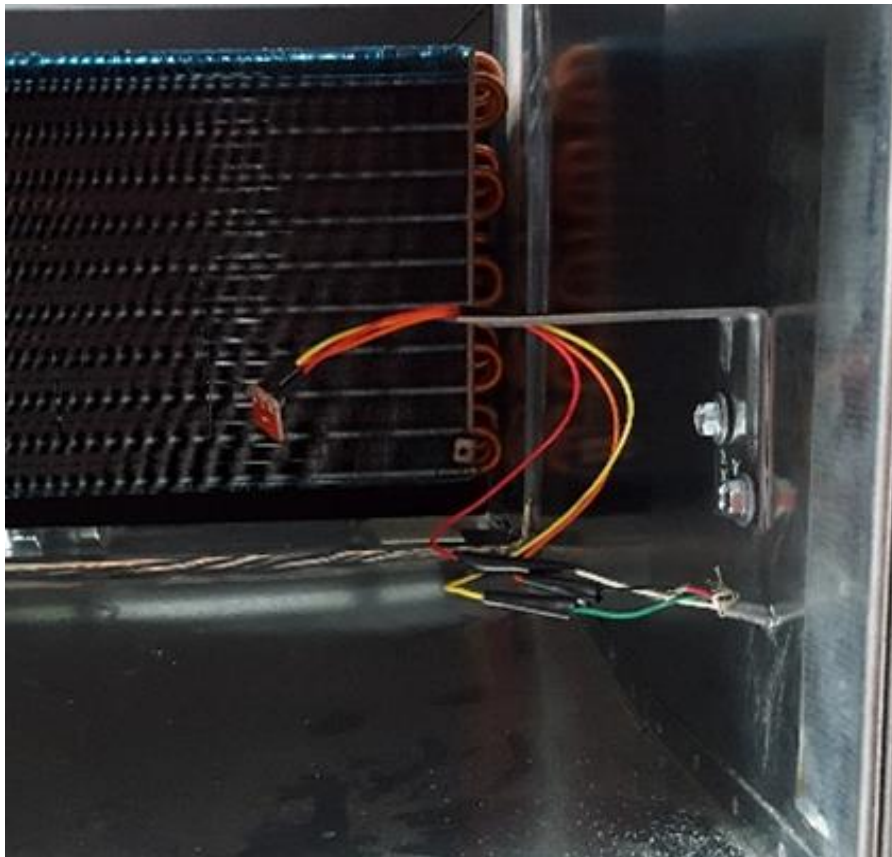


Figure 15: Humidity sensor installed

The temperature sensors were installed using a similar approach. The bottom sensor was mounted to a truss tie with the cable feeding through the back of the ductwork. It is placed just to the right of the humidity sensor. The temperature sensor on the top was fed through the top of the ductwork. The location of the sensors are shown in Figure 16. The benefit to installing humidity sensor 1 at the inlet to the condenser and humidity sensor 2 at the inlet to

the evaporator is that the values being displayed by the sensors can be compared. If the values match then no mixing occurs [15].

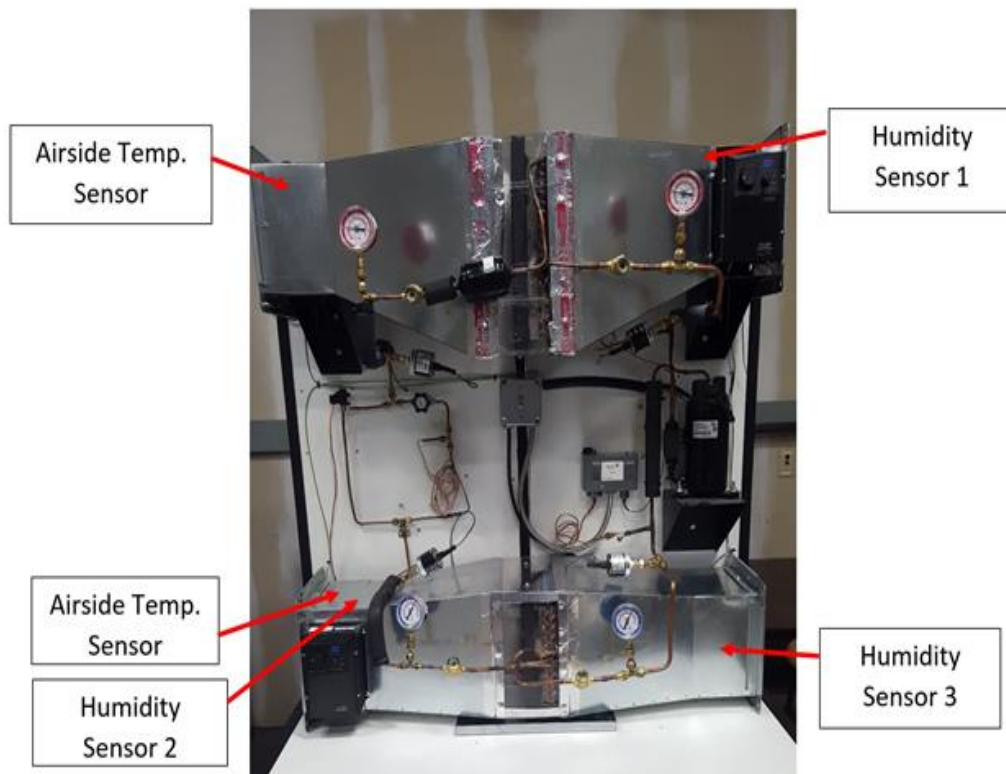


Figure 16: Airside sensor schematic

4.7 Additional Equipment Installation

The first cosmetic update we completed was installing the copper tubing support. In order to prevent the copper tubing from becoming fatigued we added truss ties for support. We secured the truss ties to the ductwork with screws, as shown in Figure 17. We then secured the truss ties to the copper tubing. In order to prevent corrosion from occurring, we added foam insulation around the copper. That way the truss ties would touch the foam and not the copper. We wrapped a cable tie around the copper tube and foam insulation and then through the hole in the truss tie in order to secure the truss tie to the copper. We placed 7 of these on the unit in various places in order to ensure the copper is supported. Now when the unit is running or moved, the copper tubing is more secure.



Figure 17: Copper tubing support installed

We also added a handle at either end of the unit so that it can be moved easily. We bought two 18" long pieces of 16 gauge steel tubing from Stillwater Steel for the handles. We attached these vertically at both ends of the frame, shown in Figure 18. We attached the steel tubes to the existing steel frame so that the handles would be sturdy. We filed the steel so there were not any sharp edges. We also added plastic caps to the ends to make sure no one would be injured. We planned to add a cut out handle to the back of the unit, but we were not able to do this once the monitor arm was mounted due to inadequate space. Figure 18 also shows the location of the monitor arm mount. This allows the user to orient the monitor into a position that is the best fit for them. This also completes the unit so it is not dependent on other accessories for setup.



Figure 18: Handle installed and monitor mounted

In order to reduce clutter under the unit we secured the power strip, computer, and mounted a wire organizer. We secured the power strip to the wall under the unit with screws in order to allow direct access to power underneath the unit. This also allowed us to cable tie any unnecessary cord length once plugged in. We also mounted the computer under the unit to secure it into place. The computer was expensive so we wanted to ensure that when the unit is moved that the computer will not be broken. The wire organizer for documentation was mounted to the unit door as shown in Figure 19. The standard operating procedure and safety data sheet were placed in the organizer to allow users to access important documentation regardless of where the unit is being used. The last item we added to the unit was the magnetic component labels. We laminated these labels and glued them to magnets so they could be added to the unit. We placed them on the unit next to their corresponding component, shown in Figure 20.



Figure 19: Wire organizer



Figure 20: Magnetic component labels

5 Final Design

5.1 Detailed Description

The unit is running at this point with no leaks. All of the sight glasses have been sealed and should not cause any further problems. The following is an overview of the cycle. The refrigerant, R410A, begins at the inlet to the compressor as a low pressure gas. The refrigerant enters the compressor and is compressed, leaving the compressor as a high pressure gas. The refrigerant then travels to the condenser where heat is lost to the outside air and the refrigerant becomes a high pressure liquid. The refrigerant then travels to the expansion valve where the flow is restricted causing the refrigerant to become a low pressure liquid. The refrigerant then flows into the evaporator where heat is absorbed, changing the refrigerant to a low pressure gas. The refrigerant then enters the compressor where the cycle begins again. These pressure and temperature drops are evident on the gauges while the unit is running. This

process can be used as a learning tool for students that is not currently offered in Thermodynamic courses. Our HVAC unit will allow students to see a working cycle, not just one on paper.

LabVIEW is updating pressure and temperature values while the unit is running. The data can also be exported in order to create both T-s and P-h diagrams for student learning tools. The air side instrumentation is installed and ready to plug into the data acquisition. The humidity sensors have been tested to ensure that they are reading accurate data after they were soldered. The cosmetic updates have been completed and the unit now has handles to help move it easier. Copper tubing supports have also been added to make sure the copper does not deteriorate when the unit is moved. The monitor has been mounted to the unit so the data can be monitored on the unit while it is running. We also created magnetic component labels in order to help the students identify the major components of the unit while going through the experiment.

5.2 Evaluation

Our group hoped to complete all of our deliverables by the end of the semester. We did complete installing airside instrumentation, displaying measured values via LabVIEW, as well as updating design flaw updates. These updates include a handle for easy movement, truss ties to secure the copper tubing, a wire organizer to organize documentation, and a monitor mount so that the monitor can be accessed while using the unit. We also completed a student experiment and the standard operating procedure for the unit. The standard operating procedure was submitted to and approved by the MAE safety board. However, we did not complete the airside instrumentation software or the expansion valve control via the arduino. We also did not complete automatic T-s and P-h diagrams.

6 Recommendations for Future Work

Future groups could add to this project by completing the arduino control for the expansion valve, completing the air nozzle selection, as well as completing and installing the air nozzle box. Our group did not complete the arduino control for the expansion valve. We plugged it in to verify that it is working, however we did not have time to work on it. LabVIEW needs to be able to be updated by the expansion valve control via an arduino interface. The airside instrumentation software needs to be completed. The sensors are installed, but they are not hooked up to the data acquisition. The software needs to be completed so these sensors display the data in the LabVIEW user interface.

Future groups could also work on adding airside flow rate instrumentation. Our group started the calculations for the air nozzle selection, however we did not finish it. Our scope was changed after our progress report so we did not continue working on the calculations in order

to complete them. We completed calculations for the required diameters, however we did not include pressure or any other necessary parameters. Future groups could work on completing the air nozzle selection, as well as completing an air nozzle box for the unit.

7 Budget Summary

Table 3 shows our final expenses. All of the funds that ASHRAE provided for this project were used by previous groups. We were given \$60 per group member in order to complete this project. We spent a total of \$91.83 of the allowed \$120.00.

Table 3: Final account of items purchased.

| | Item | Item # | Cost per unit | # of units | Total Cost | Purchase Location | Specifications |
|---|-------------------------------|----------------|---------------|------------|----------------|-------------------|-----------------|
| 1 | Steel Tubing | | N/A | 2 | \$3.95 | Stillwater Steel | 1 SQ x 16 gauge |
| 2 | Humidity Sensors | HIH-4030 | \$16.95 | 3 | \$50.85 | sparkfun.com | |
| 3 | 5V power supply | TOL-12889 ROHS | \$5.95 | 1 | \$5.95 | sparkfun.com | |
| 4 | Self tapping Screws | 59183 | \$5.58 | 1 | \$5.58 | Lowes | 1.5 inch |
| 5 | Black furniture tips (2 pack) | 37856 | \$1.99 | 2 | \$3.98 | Lowes | 1 inch square |
| 6 | Copper support (truss tie) | 194957 | \$0.65 | 9 | \$5.85 | Lowes | |
| 7 | Black paint | 384317 | \$4.98 | 1 | \$4.98 | Lowes | |
| 8 | Mesh Organizer | 694147116211 | \$9.82 | 1 | \$10.69 | Walmart | |
| | | | | | | | |
| | | Total | | | \$91.83 | | |
| | | Allowed Budget | | | \$120.00 | | |

8 Current Events

ASHRAE is holding a training in August that will focus on improving existing building operation. It will specifically focus on improving existing HVAC systems. They will talk about potential improvements that can be made in order to get the most out of your unit. Owners are trying to reduce expenses by maximizing efficiency and increasing performance. In order to keep the unit running, proper operation and maintenance must be performed. The training will provide information on how to do this [16]. This is relevant and important to our unit because the goal is for it to last for at least 10 years. In order for our unit to last, proper maintenance must be performed to keep it up and running.

9 Appendix

Figure A.1 [17]

5.3 Access by reaching through an opening in a guard

The safety distance determined between the danger zone and the guard in the case of access through the guard (see Figure 5-4) is a function of the dimension and shape of the opening.

The following symbols are used:

- ▶ «sd» is the safety distance, namely the distance between the guard and the danger zone;
- ▶ «e» is the smallest dimension of the opening.

5.3.1 Openings in the guard

The guards may include regular-shaped openings (square, round, slot- or groove-shaped) or irregular-shaped openings for feeding the machine or for viewing the danger zone or the process.

Dimension “e” corresponds to the smallest dimension of a rectangular (slot-shaped) opening, to one side of a square-shaped opening, and to the diameter of a circular-shaped opening (see Figure 5-5).

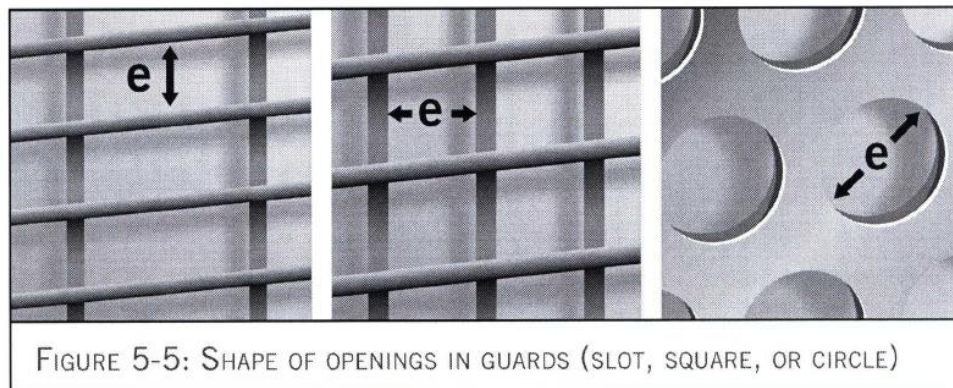
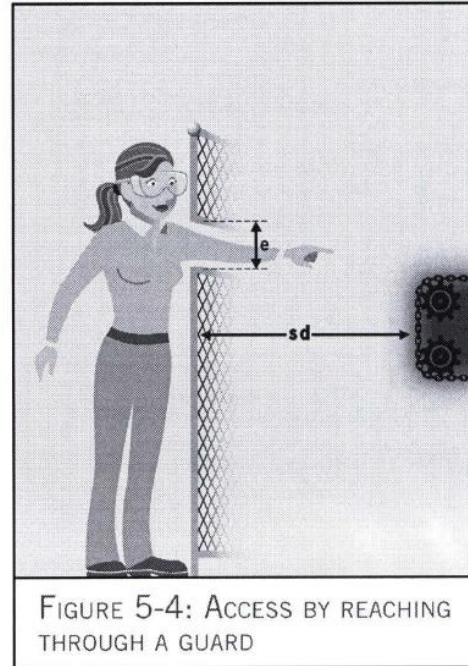


Table 5-3 is used to determine:

- ▶ the maximum acceptable opening (shape and dimensions) in relation to the chosen safety distance "sd";
- ▶ the safety distance "sd" as a function of the existing opening (shape and dimensions).

TABLE 5-3: RELATIONSHIP BETWEEN MAXIMUM OPENING AND SAFETY DISTANCE "sd"

| Slot or groove shaped opening (from CSA Z432-04 [21]) | | | |
|---|----------------------|--------------------|-----------------------------------|
| Safety distance "sd" (mm) | Maximum opening (mm) | Opening (mm) | Minimum safety distance "sd" (mm) |
| Less than 13 | S. O.* | From 0 to 6 | ≥ 13 |
| From 13 to 63,9 | 6 | From 6,1 to 11 | ≥ 64 |
| From 64 to 88,9 | 11 | From 11,1 to 16 | ≥ 89 |
| From 89 to 165,9 | 16 | From 16,1 to 32 | ≥ 166 |
| From 166 to 444,9 | 32 | From 32,1 to 49 | ≥ 445 |
| From 445 to 914,9 | 49 | From 49,1 to 132** | ≥ 915 |
| ≥ 915 | 132** | | |

| Square opening (from CSA Z432-04 [21]) | | | |
|--|----------------------|--------------------|-----------------------------------|
| Safety distance "sd" (mm) | Maximum opening (mm) | Opening (mm) | Minimum safety distance "sd" (mm) |
| Less than 13 | S. O.* | From 0 to 6 | ≥ 13 |
| From 13 to 47,9 | 6 | From 6,1 to 11 | ≥ 48 |
| From 48 to 65,9 | 11 | From 11,1 to 16 | ≥ 66 |
| From 66 to 165,9 | 16 | From 16,1 to 32 | ≥ 166 |
| From 166 to 444,9 | 32 | From 32,1 to 49 | ≥ 445 |
| From 445 to 914,9 | 49 | From 49,1 to 132** | ≥ 915 |
| ≥ 915 | 132** | | |

| Round opening (from ISO 13852:1996 [19]) | | | |
|--|----------------------|-------------------|-----------------------------------|
| Safety distance "sd" (mm) | Maximum opening (mm) | Opening (mm) | Minimum safety distance "sd" (mm) |
| Less than 2 | 0 | 0 - 4 | ≥ 2 |
| From 2 to 4,9 | 4 | 4,1 < e ≤ 8 | ≥ 5 |
| From 5 to 19,9 | 8 | 8,1 < e ≤ 10 | ≥ 20 |
| From 20 to 79,9 | 10 | 10,1 < e ≤ 12 | ≥ 80 |
| From 80 to 119,9 | 12 | 12,1 < e ≤ 40 | ≥ 120 |
| From 120 to 849,9 | 40 | 40,1 < e ≤ 120*** | ≥ 850 |
| ≥ 850 | 120*** | | |

* Guards shall not be located less than 13 mm from the hazard.

** The maximum size of a slot- or square-shaped opening is 132 mm.

*** The maximum size of a circular or irregular-shaped opening is 120 mm.

Note. – CSA Z432-04 does not discuss the case of circular or irregular-shaped openings, and hence the reference to ISO 13852:1996. However, note that these two standards contain different limit values.

Figure A.2

Fan Cover Calculations

Maximum square opening: 0.5 in = 12.7 mm

12.7 is between 11 and 16 mm range

Minimum safety distance is between 48 and 66 mm range

Interpolate:

$$\frac{12.7 - 11}{16 - 11} = \frac{x - 48}{66 - 48} = 54.1 \text{ mm} = 2.13 \text{ in}$$

After measuring the actual fan cover, it is 2.25 in from the fan blades. $2.25 \text{ in} > 2.13 \text{ in}$

It exceeds the minimum safety distance and does not need to be changed.

Figure A.3



10 References

1. Tang, T.J., Lu, C., and Risteen, N. Capstone Design. pp. 34. 2015.
2. Powers, S., Grundman, J., Spruiell, S., and Weyand, J. HVAC Refrigeration Unit Progress Report. pp. 4. March 23, 2016.
3. Reese, C., Juliano, M., and Carriger, B. HVAC Demonstration Unit. pp. 8-9. 2015.
4. Energy Standard for Buildings except Low-Rise Residential Buildings. *ASHRAE STANDARD*. Standard 90.1-2013. pp. 64. 2013.
5. Setra. Setra Systems. 2016. <http://www.setra.com/>. Accessed June 21, 2016.
6. Mouser Electronics. HIH-4021-002. 2016. <http://www.mouser.com>. Accessed June 27, 2016.
7. Spark fun. HIH-4030. 2016. <https://www.sparkfun.com/products/9569>. Accessed July 20, 2016.
8. Mouser Electronics. US Sensor PPG102A1. 2016. <http://www.mouser.com>. Accessed June 27, 2016.
9. Lowe's. Roof truss tie. 2016. <http://www.lowes.com/pd/USP-1-1-4-in-x-2-in-x-2-3-4-in-Roof-Truss-Tie/3692082>. Accessed July, 20 2016.
10. Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment. *ASHRAE STANDARD*. Standard 37-2009. pp. 6-7. 2009.
11. Standard Method for Temperature Measurement. *ASHRAE STANDARD*. Standard 41.1-2013. pp. 8. 2013.
12. Standard Methods for Laboratory Airflow Measurement. *ASHRAE STANDARD*. Standard 41.2-1987, 92. 1987.
13. Occupational Safety & Health Administration. Regulations. Standard 1910.212. https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9836. N.d. Accessed June 30, 2016.
14. Safety of machinery. *International Organization for Standardization*. Standard 13857:1996. pp. 1-17. 1996. <https://law.resource.org/pub/ip/ibr/jis.b.9707.e.2002.pdf>. Accessed June 23, 2016.
15. Bach, C. Personal e-mail sent from Dr. Bach. Subject: MAE 4344 - S16: Daily update 7/20/16. cbach@okstate.edu. Sent July 21, 2016.
16. ASHRAE. Improving existing building operation. ASHRAE. <https://www.ashrae.org/education--certification/hvac-design-and-operation-training/improving-existing-building-operation>. 2016. Accessed July 24, 2016.
17. Giraud, Laurent. Machine Safety. pp. 38-39. 2009. <http://www.irsst.qc.ca/media/documents/pubirsst/RG-597.pdf>. Accessed June 23, 2016.

18. Young, Trevor M. *Technical Writing A-Z: A Commonsense Guide to Engineering Reports and Theses*. New York, NY: ASME Press. 2005.