Building Automation Teaching Tool

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

Johnathon Wagner

Advisor: Ahmed Elgafy Ph.D

April 26th, 2024

TABLE OF CONTENTS

LIST OF FIGURES

ABSRACT

The topic expressed in this paper is one specific to EMCOR Services and our group. All the new CO-OPs, Install and Engineers would usually be lacking any hands-on experience who are just learning about Building Controls. Of course, there is nothing quite exactly like we are trying to build though we do have the typical models of an Air Handler and a VAV unit to model from. What was decided was to have a mock system with Automated Logic Controls and Sensors to better give new staff something to learn from and experiment with. After some field changes the final setup was complete and tested resulting in a working product just in time for the new coops this summer.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

The issue this machine will address is the lack of hands-on ability for new controls Co-Ops, Engineers and installers who are just learning about Building Controls.

BACKGROUND

In the last 2 years, I have worked at EMCOR Services Automated Controls, it has been brought up countless times of our lack of sufficient technologies to train installers and co-ops on the basic equipment of the field. As a result, there are many Co-Ops who do not have a complete education of the needed field information to understand what exactly we do as a company. What EMCOR wants to do is to have a simple training device to teach new staff and Co-ops what a simple air handling system does and what typical components are found in this system. They want to be able to allow new hires to safely be able to mess with a device without harming products that are installed for customers. The final Device will be a designated Teaching Tool.

RESEARCH

SCOPE OF THE PROBLEM

The problem is simple. EMCOR needs a device to help new staff learn about the simplest system we come across. An Air Handler and a VAV box. Each device, controller and wire will be specific for what type of devices EMCOR uses. This device is only to train new people. Though it will also include history on the subject for new staff to be able to learn.

Modern HVAC began many years ago with Willis Carrier in 1902 when he created the first AC unit for the Buffalo Forge Company by either heating or cooling water across a coil

(1). In the 1920s, refrigeration was becoming a more popular cooling technique, specifically R12 (2). This allowed Carrier to introduce a Centrifugal chiller to cool the water (1). This was used to cool theatres and was the next big step into today's cooling systems! Continuing Frigidaire and General Electric worked to make room and home AC units through the late 1920s and 1930s (3). Though we are more looking at the commercial industry. As time progressed units became more and more sophisticated and we grow to see today's units. Though a unit still needs a way to control, that's where we get to the Direct Digital Controls.

Looking to the Direct Digital Controls that will be controlling devices we look to a more specific brand, Automated Logic Corporation, A Carrier Company. In 1977, ALC was founded and would go on to manufacture building automation systems. The major system that is being used today is the WebCTRL web-based software. This software allows building supervisors to manage all systems, HVAC, lighting, fire and security all in one system (4). Specifically, we will be focusing on the HVAC portions of WebCTRL.

STANDARDS

- UL Listed (global safety science company)
- ASHRAE (The American Society of Heating, Refrigerating and Air-Conditioning Engineers
- IBEW Code of Excellence (International Brotherhood of Electrical Workers)
- BACnet EN ISO 16484-5
- Modbus ANSI EIA/TIA-485
- LonWorks ISO/IEC 14908

CURRENT STATE OF THE ART

For our state-of-the-art there are a few sections. The air handler itself and the terminal unit. For the air handler a common unit is made by carrier. As previously stated, Carrier is one of the leading HVAC manufacturers for both residential and industrial use. The specific unit we will be reviewing is the AERO® Indoor Air Handler as seen below. A pro to this model would be the easily accessible coil compartments. This makes it very easy for us to attach our

valves. A con to the model is the sirectio of the supply and return. It has a straight design which only gives a certain position to have ductwork mounted to it.

Figure 1 An Aero Simple Air Handler with 2 Compartments

This is a relatively simple unit that can be used in heating, cooling and VAV applications (5). Looking to another large unit, Trane is a large leader of the pack. For a good comparison I am looking at Catalog Air Handlers. (6)

Figure 2 A Trane Simple Air Handler with an External VFD Case

The above units are the main product, the Air Handler. These devices are what treat and allow air movement for a room or set of rooms. A Pro to the Trane unit is the external VFD cabinet. This allows all the devices to be run along the unit must easier. A con would be this

specific unit does not seem to have easily accessible coil hookups. Comparing these two units we see they are both compact and relatively inexpensive. Both units would be used for a small space like a conference room or multiple small offices. Trane and Carrier are two large corporations that manufacture much bigger units as well.

Now for terminal units the most popular is the Titus branded box. This box is a simple single duct with no reheat. This is a model DESV(7). A pro of this design is the front access for the addition of an electric or hot water reheat coil. This allows a single model to be used for reheats as well. A con to this design is the exposed Damper linkage. Due to not being covered there are different specifications required when running the plenum wire and how the module needs to be mounted to the box.

Figure 3 A Titus Model Desv Simple VAV

The second bigger manufacturer is Carnes. Their model AVCD is another single duct with no reheat. (8) A large pro to this box is the side mounted controls cover. This allows our controls to be safely stores away. The con is the lack of airflow tube leads. This adds slight difficulty in requiring the controls contractor to add pneumatic tubing to the small spouts on the air flow ring.

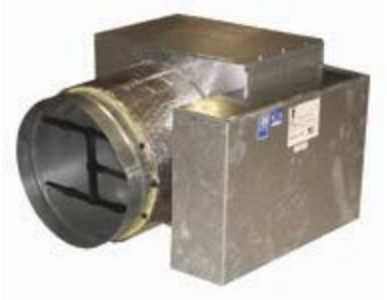


Figure 4 A Carnes Model AVCD Simple VAV with Controls Cover

Comparing the two terminal units and what they're for is quite simple. These would be installed at the room level and have their intake connected to the Air Handler. Both units are cooling only. This means that they do not add any extra heat. They only modulate airflow to satisfy the room temperature. Looking at both units they're relatively identical. Both come with airflow tubes to be connected to a controller and both have a damper with an extended shaft. The only difference is the visuals. The Carnes box has an added case to house the controls whereas the Titus pictured does not. This would mean the controls being installed would need to be plenum rated on the Titus unit.

END USER

The end user is very general. Any new employee of EMCOR Services as well as any existing employee who wishes to use the system to test would be using this device. Due to the nature of wanting to create a hands-on device, the priority will be used by new staff. Due to this the device must be easy to understand. As well as many explanations in the software as to what each device is. We also want to make sure the user is safe, as they will be using the device with little supervision.

Though the user will be looking for an educational experience. So, each portion of this device will need to be well thought out for the better understanding of the user.

CONCLUSIONS AND SUMMARY OF RESEARCH

Looking over the research from above, we learned the history and the current standards of Air Handlers and Terminal units in the commercial industry. With the given knowledge we can develop a device for EMCOR to be able to train new hires on these typical field units. It must be remembered that this device is for the learning purposes of EMCOR staff and will assist with making a brighter future for the new hires. In Conclusion of this research, I can take the history and use of HVAC and Automated Logic to help better create this teaching tool for EMCOR so all can continue to learn as intended.

CUSTOMER FEATURES

Speaking to Managers and the senior engineers they came up with a list of features to be used. They go as follows. They specifically asked for the device to be easily accessible, programable, configurable, cost effective, and self-sufficient.

ENGINEERING CHARACTERISTICS

For engineering characteristics, I discussed these with one of the senior engineers. Specifically, we will be using Automated Logic Boards because that is the only type of controller we sell. We will be building the unit on wheels to make it easy to move. We will be using existing sensors and refurbished materials to assist with the cost-effective section. The fine section is quite easy. Labels. They seem easy but will allow the unit to be self-sufficient. We can allow a new person to just play and read labels. A sort of teaching themselves.

PRODUCT OBJECTIVES

The addressing of the customer features is a quite simple answer. Due to the project being

specifically for EMCOR, I do not have to worry about other parties not agreeing with the final decision. All project decisions and designs will be run through the management of EMCOR specifically out of the Columbus office. It will also be manufactured under the general supervision of the office. Because of this there will not be any occurrence of missing features or needing to rule out complicated features. Every feature has a specific purpose.

EMCOR as a company usually tries to be cost effective and be the most efficient. Because of this they requested specific pieces to be used and implemented.

QUALITY FUNCTION DEPLOYMENT

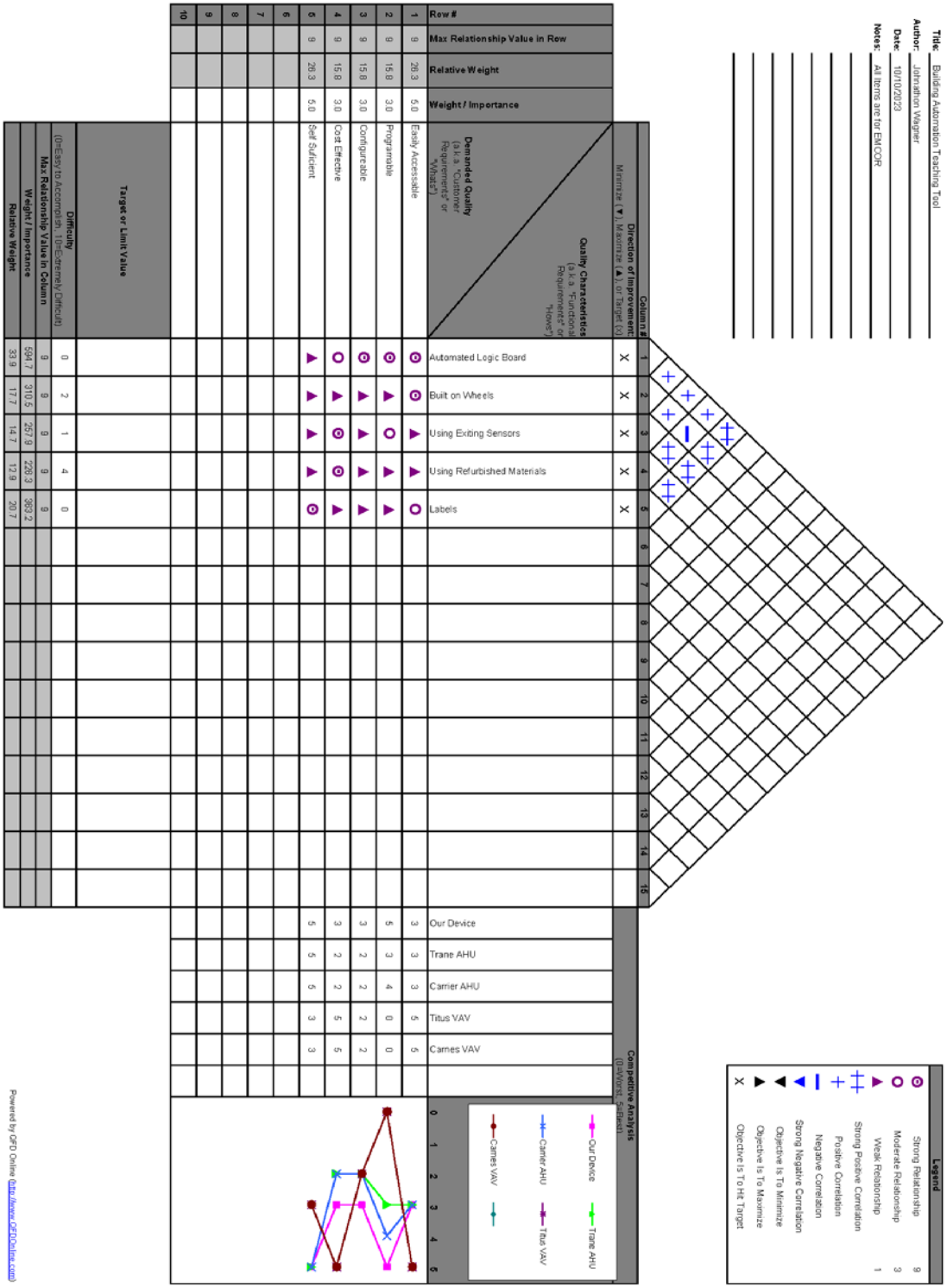


Figure 5 QFD

DESIGN

The Design alternatives and final selection is a bit different compared to a typical design process. Due to this project being a direct device for EMCOR Services Automated Controls, the Engineering Manager, Matt Buelow and the Senior Engineer, Dale Meeks, worked with me to get the exact design they wanted in the beginning. All the major details were run through them before a design was completed. Once we had a design they wished to pursue, the University of Cincinnati Faculty was notified through the submissions of Senior Design I and II.

The Selection was finalized as a simple AHU with Supply fan. It would consist of 2stages of heating, 2 stages of cooling, temperature sensors, dampers, and a VAV with integral flow metering. This list was selected in order to have a well-balanced tool to better prepare new staff and follow our final goal.

From this point a simple hand drawn sketch was created and soon worked to a CAD model as shown below in Figure 6 and Figure 7 The compact design and wheels help to make this a well-rounded tool.

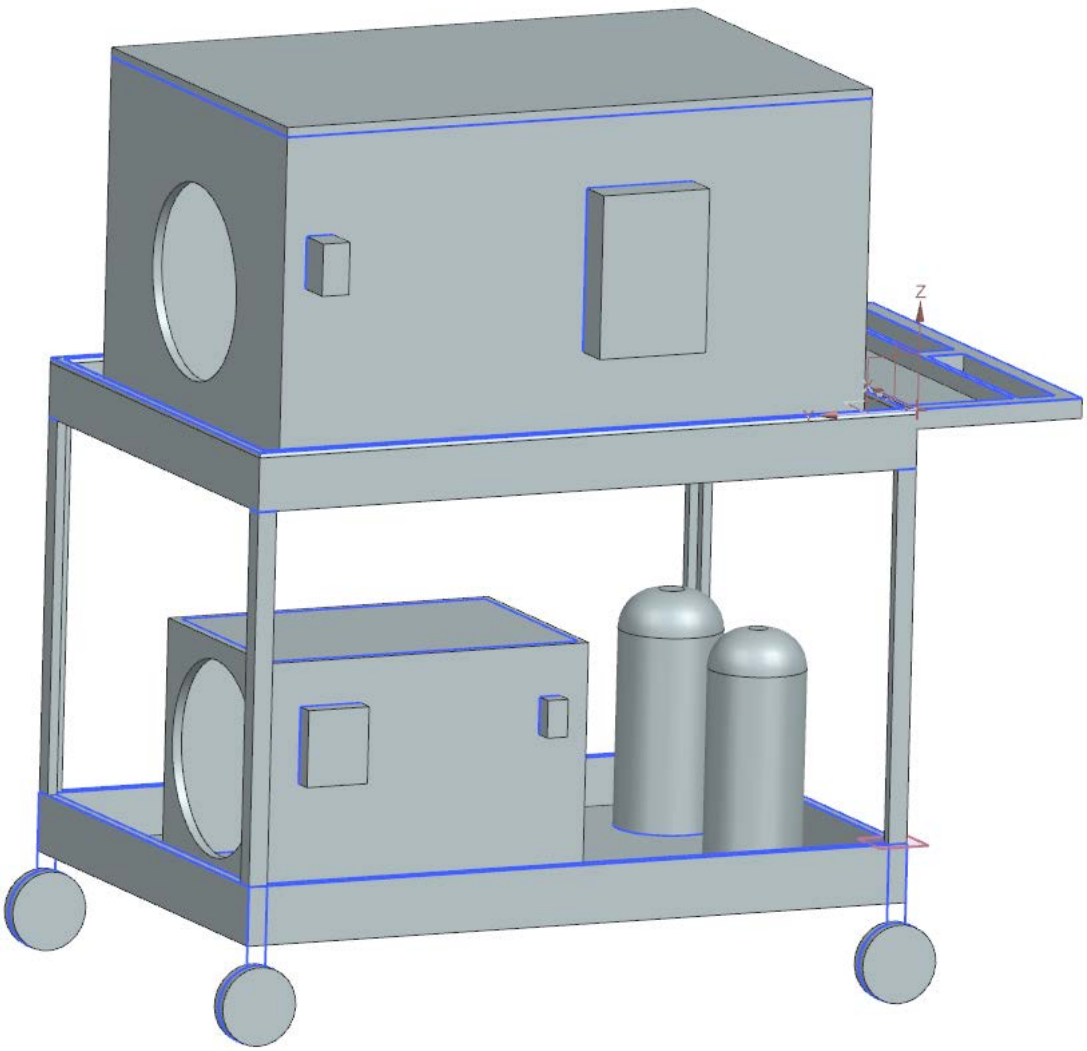


Figure 6 Side View of the Building Automation Teaching Tool

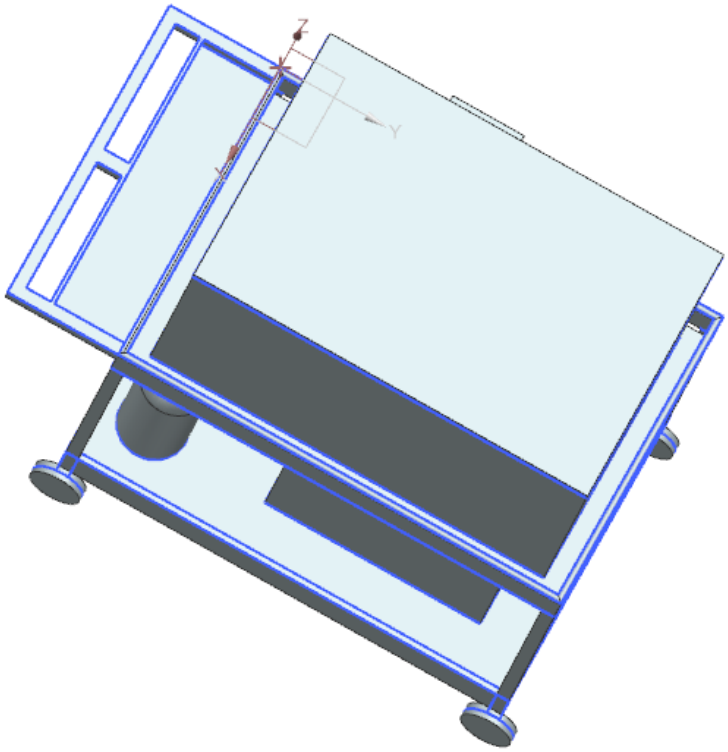


Figure 7 Top-Down View of the Building Automation Teaching Tool

From our Model, we then must move to the component selection. The main reason for this is because this project is a reverse engineering style of opportunity. EMCOR Services Automated Controls is providing a lot of the pieces and parts for this job, which we will get into more detail later in this document. So, we must see what parts we have and how we can ensure they are sized correctly for our application. Most of the devices are Automated Logic, ALC branded. This is due to us being a dealer for the company and the main need for our tool. There is no alternative to these parts. These are used for the Controllers and temperature sensors. For our Damper actuators we are going with a Belimo branded device. The reasoning behind this is due to the standards of EMCOR and Building Automation. Belimo is

a top seller in actuators and the only supply we buy actuators from for all of our applications at EMCOR Services Automated Controls. Sheet Metal is not a specific part though it is known that it will be Galvanized Mild Steel with a Zinc coating on the exterior. This specifically is from our sister company, Debra-Kuempel, as they are a mechanical contractor. And finally, the cart. We chose to go with a Huskey Utility Cart - 12603. This is a leader in other carts that we use in our shops and a great option due to its weight capacity of 500 lbs. Below is the Bill of Materials generated through our programming to show part numbers and counts. See Figure 8.

Bill of Material				
Vendor	***Part Number***	***Product Description***	***Manufacturer***	***Quantity***
Belimo	TFB24-SR	Damper Actuator, 22 in-lb [2.5 Nm], Spring return, AC/DC 24 V, modulating, 2...10 V	Belimo	2
Huskey	12603	Uline Utility Cart - 45 x 25 x 33", Black	Huskey	1
Automated Logic	OFBBC	BACnet Building Controller, supports up to nine expanders	Automated Logic	1
Automated Logic	FIO812u	I/O Expander, 8 UO, 12 UI	Automated Logic	1
Automated Logic	NSB-10K-2-D-8-BB2	Duct, 8" Insertion, 10' Leads	Automated Logic	2
Automated Logic	NSB-10K-2-H200-D-BB2-A	2%RH, Box Enclosure 10K-2 Thermistor, 0 to 5 or 4 to 20 mA %RH Output	Automated Logic	1
Debra-Keumpel	Sheet Metal	Sheet Metal(For Box, Dampers)	Debra-Keumpel	N/A
Windy City Wire	002320-11	18 AWG 2 Conductor Shielded Plenum White Jacket with Black Stripe	Windy City Wire	200
Automated Logic	ZN341A	Zone Controller for VAV w/ Actuator, 3DO, 4UI, 1AO	Automated Logic	1

Figure 8 Bill of Materials

Now for our Analysis. Firstly, is the weight of the design. It is speculated, with the weight of all individual items, that at our extreme we will be no more than 300lbs, this is including the weight of the cart. The Cart has a max holding capacity of 500lbs. Using our formula in Figure 9, we calculate a Factor of safety for this design getting to 1.66.

$$\text{Factor of Safety} = \frac{\text{Actual Capacity}}{\text{Demand}}$$

Figure 9 Factor of Safety Formula

Next is our electrical load. These are pulled without calculations and instead verified directly on the units provided by EMCOR. We of course want to only power off of 120Volts AC. For our load of the unit, we find that heating will use 7.5 amps, and cooling will use 3.21

amps with control devices using no more than .4 amps at max.

Capacity is the next style of load to go over. We received a cooling coil at a 5000 BTU rating. Doing the calculation pictures in Figure 10 we come to find the given CFM is roughly 200.

$$cfm = \frac{BTU/hr}{1.08 \times \Delta T}$$

Figure 10 CFM Sizing Formula

Heating was given at 750-Watt Capacity. Using Figure 11 and the given 200 CFM capacity for cooling we came to conclude that a 750-Watt capacity would also give us ~100 CFM.

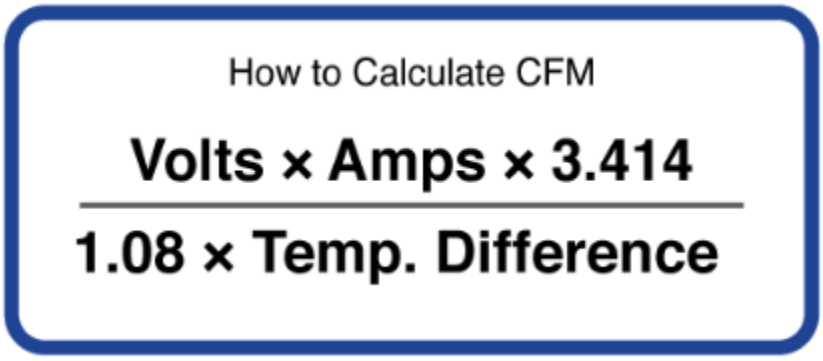


Figure 11 Heating CFM Formula

For the process of assembling the Teaching Tool, Myself as well as the Senior Engineer will be working out of the Columbus office. We will not need any special physical tools, though we will be using the WebCTRL Software required for programing the Automated

Logic controllers. This requires a license that is already owned by EMCOR. As well as due to the fact we are dealing with Refrigerant, we must be careful of our safety. Luckily the shop is already equipped with Refrigeration Monitoring from the other work done by our sister company, Debra-Keumpel.

For Testing there are 2 stages. The first is an initial checkout ensuring that the device is properly wired, stable and equipped with its default program. An Added item is to include an instruction booklet along with the already described Labeling from the QFD. Once we know the unit is ready, we can then allow anyone to have at it! This is designated for newer or inexperienced employees so the best course of action to ensure this design is working is to let them use it as intended!

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

The budget is split into two parts for this work. Theres the value for EMCOR and the value I would be paying out of pocket. With all the controllers and devices, as well as all of the equipment, EMCOR has a budget range of $5-6 thousand. This is as close as can be calculated due to all the individual equipment already being owned by EMCOR to some extreme. As for the personal budget we calculated a value of $500. This is using Man Hours required, Tools and materials such as screws. In the coming months we will log how much we spend in total. In All Actuality, The EMCOR budget was as expected though my own budget spent was actually $1000… Now why did we double out Budget? Sadly, this was due to an issue with transport related to the expo and not with the design itself. The van required for the transport of the unit was in the shop and instead we had to get a Rental from U-Haul to bring it down for the expo. Otherwise, we would of stayed within budget.

SCHEDULE, PROPOSED /ACTUAL

There are a few key items to look at for our schedule. Firstly, there is a set start date of January 8th, 2024, with a Tentative Completion Date of March 1st 2024. Now this is a very long range of time for not as much work. Though the frame is long due to who is doing the work and when it will be done. All the assembly will be sone by Dale Meeks and myself. With the Initial Programming for the Tool to be done by myself. Due to us both being Employees at EMCOR Services Automated controls, work comes first. And with that the Senior Design building will be done during the evenings and weekends. Hopefully we will

finish much faster than the initial end date. Now in actuality, I got bored over Winter Break, So Dale Meeks and I got to work early and had everything done by Mid-January after devices got in. So, we finished way ahead of schedule.

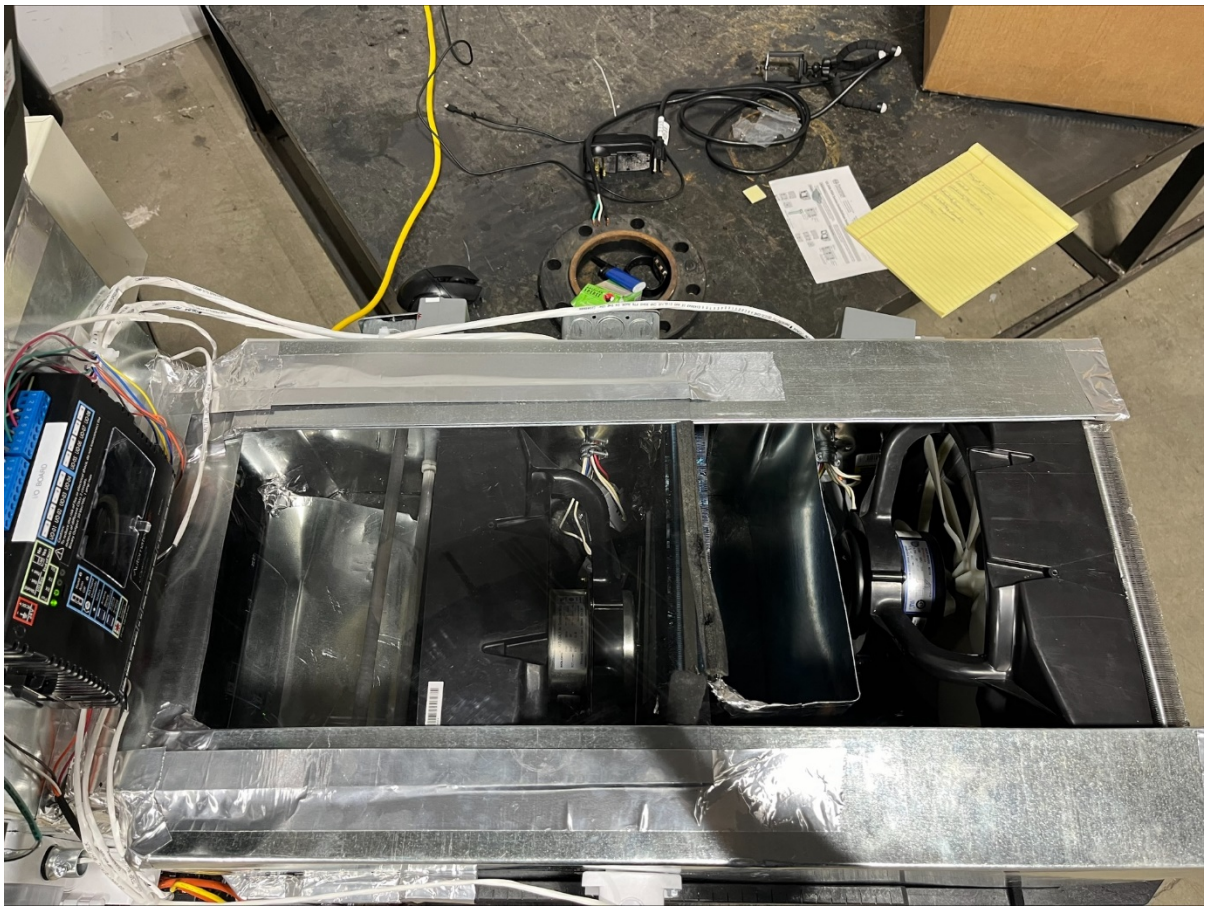
SUSTAINABILITY AND MATERIAL USAGE

There are 2 big factors that could have made this project more efficient. Firstly, the wire leads would have been much easier to work with on the 120V side if they were longer. Though the motors we had only had a specific lead length. And secondly if I were to do it again I would have wished to get a wider cart. This model does not have as much width as it should to make it easy to change out motors and coils.

FINAL PROJECT VIEW

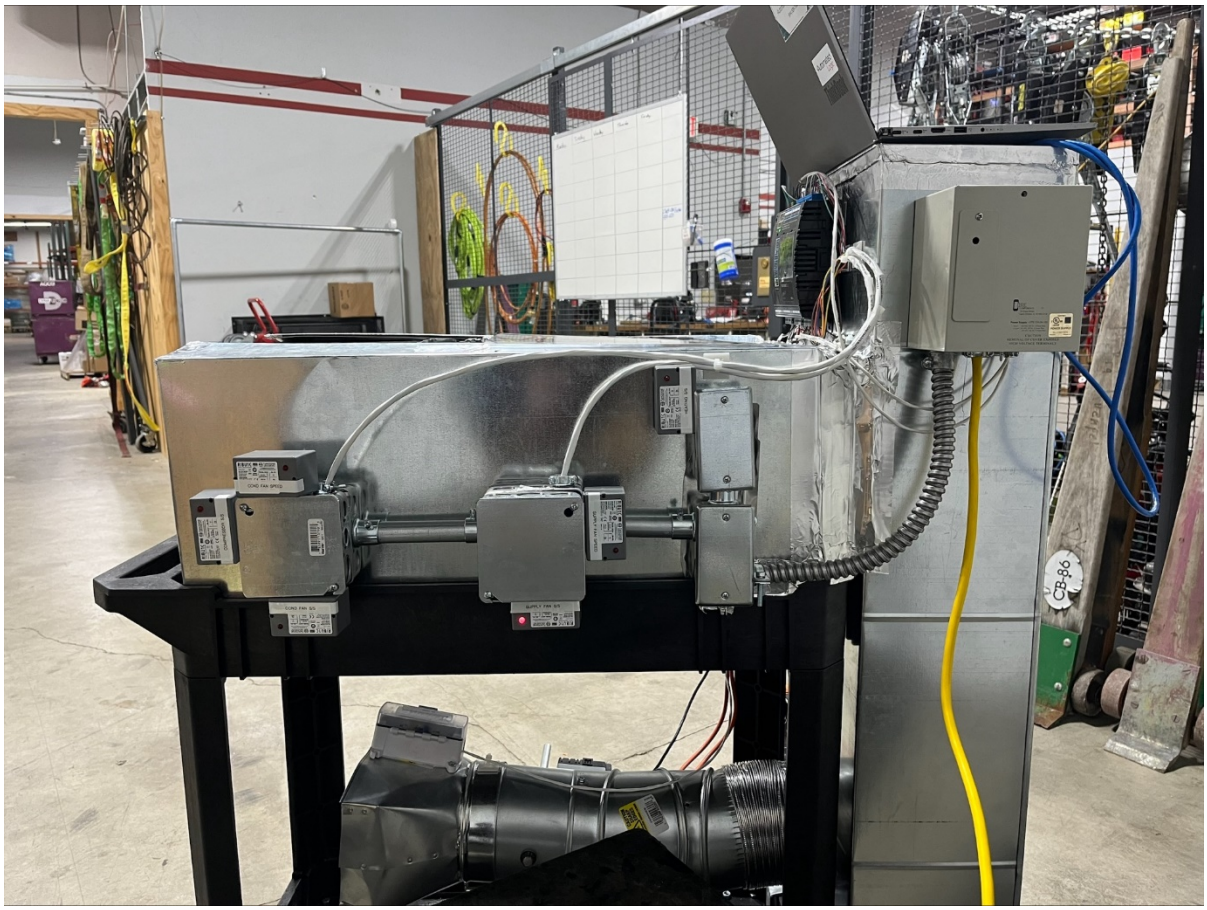
The final Project was a bit of a design change. Rather than having the compressor on the bottom, it was instead on the top with our discharge sensors in a vertical main trunk. Below are the images from the project.


Automated Logic
ThinkBook
AutomatedLogic
OptiFlex
I/O Expander

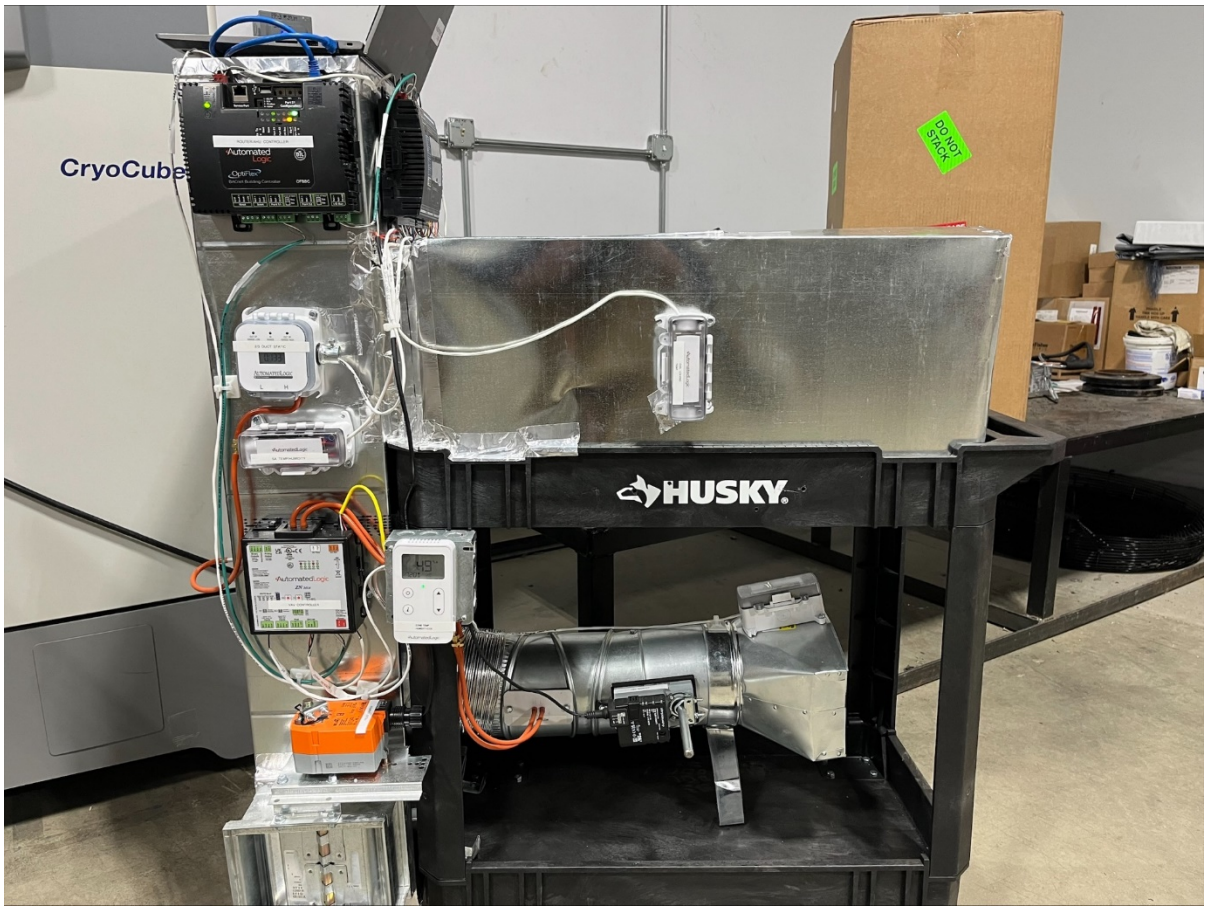



ROUTER/AHU CONTROLLER
Automated Logic
OptiFlex
BACnet Building Controller
OFBBC
Rnet
Xnet
Port S1
Port S2
I/O Bus
2/3 DUCT STATIC
AUTOMATEDLOGIC
L
H
AutomatedLogic
SA TEMP/HUMIDITY
AutomatedLogic
ZN 341A
VAV CONTROLLER
ZONE TEMP
HUMIDITY/CO2
AutomatedLogic


ThinkBook
Cube
SUPER
FLOW




VAV DAMPER
AIRFLOW
Automated Logic


CryoCube
Automated Logic
DO NOT STACK
HUSKY

WORKS CITED

1. **History of air conditioning: A brief HVAC history - when & how.** ***Trade School Programs in Chicago.*** **[Online] May 23, 2022. [Cited: September 15, 2023.] https://www.coynecollege.edu/a-brief-history-of-hvac-air-conditioning.**
2. JESTINE. What is Refrigerant R12. ***Refrigerant Finders.*** **[Online] March 24, 2022. [Cited: September 15, 2023.] https://refrigerantfinders.com/what-is-refrigerant-r12/.**
3. History of the commercial HVAC unit. ***EnviroUSA.*** **[Online] June 17, 2021. [Cited: September 15, 2023.] https://www.envirousa.com/history-of-the-commercial-hvac-unit.**
4. Logic, Automated. Automated Logic - About. ***Automated Logic.*** **[Online] [Cited: September 15, 2023.] https://www.automatedlogic.com/en/success-stories/automated-logic/#:~:text=Automated%20Logic%20Corporation%20was%20founded,energy%20efficient%2C%20and%20more%20comfortable..**
5. Carrier. Aero® Indoor Air Handler 39L: Carrier Commercial Systems. ***Carrier.*** **[Online] [Cited: September 15, 2023.] https://www.carrier.com/commercial/en/us/products/airside/air-handlers/39l/.**
6. Trane. Catalog air handlers: Industrial HVAC heating and Cooling. ***Trane Heating & Air Conditioning.*** **[Online] [Cited: September 15, 2023.] https://www.trane.com/commercial/north-america/us/en/products-systems/air-handlers/performance-air-handlers/ucca.html.**
7. Titus. DESV. ***Titus.*** **[Online] [Cited: September 15, 2023.] https://www.titus-hvac.com/Products/Terminal%20Units/DESV.**
8. Carnes. Model AVCD. [Online] [Cited: September 15, 2023.] https://www.carnes.com/TerminalUnits/avcd.phtml.