9/11/2020

EML4551-2

Team 510: Indoor Air Quality of Hotspots

Eric Grogans;Leon Johnson;Emma Martin;Razhan Matipano;Whitley Pettis

FAMU-FSU College of Engineering 2525 Pottsdamer St. Tallahassee, FL. 32310

Abstract

As schools and universities return to in-person learning amid the COVID-19 pandemic, air quality is an important topic. Our sponsor, Honeywell, wants to explore how to improve air quality in indoor spaces. This project's goal is to lessen the spread of harmful particles present in the air of university classrooms, namely COVID-19. This project aims to measure and adapt air quality in the FAMU-FSU College of Engineering. Air will be adjusted to promote a healthy building climate without changing the existing air handling system. We are measuring and adjusting air quality using equipment on a pair of portable carts. Each cart contains a set of cleaning and sending devices. One cart is intended for long-term use in the same location, while the other is intended for short-term use in many locations. We chose this concept because of its portability. A portable design allows users to easily transport the equipment around the college. We can temporarily place the carts in a room to study and adjust air quality. The carts can then be moved to new spaces as needed. Users can easily track air quality during different times of day. When higher levels of pollutants are present, operators can adapt device settings to best suit each room. The project can track how specific activities and varying occupant levels effect air quality. A computer displays the recorded data to users. Operators can use data to choose when to run the equipment. Running the device only when air quality is low boosts the efficiency of the project by lessening unnecessary use. This project can be used in locations other than schools and universities. In the future, we can scale this project for use in hospitals, stadiums, and other high traffic public spaces which are seeing an increase in face-to-face contact.

Keywords: air quality, hotspots, measure, modify

Acknowledgement

We would like to begin by thanking our sponsor, Honeywell. They have been instrumental in the completion of this project by donating their time, money, and resources. All our equipment was donated by Honeywell, helping ensure our project's completion to the highest possible standard. There are also several individuals within Honeywell who have been incredibly helpful. Danny White has been working behind the scenes to make sure we have everything we need. Alfred Guerrero and Danny Mims have been a consistent source of expertise, taking the time to meet with us every week and answer all our questions. Special thanks also go to Carlos Ribot who came all the way from St. Augustine to help us put our equipment together and explain how it all works.

We would also like to thank our advisors, Dr. Neda Yaghoobian and Dr. Shayne McConomy. Dr. Yaghoobian has helped us to answer countless technical questions as well as making suggestions that have been key in shaping the project. Dr. McConomy has been especially helpful throughout the project. He has been available to help with anything we need at a moment's notice, project related or not. We are very thankful to have been supported by two such amazing faculty members over the past year.

Table of Contents

List of Tables

List of Figures

Notation

AHP	Analytic Hierarchy Process
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
CDC	Centers of Disease Control and Prevention
CFD	Computational Fluid Dynamics
COE	College of Engineering
COVID-19	Coronavirus Disease from 2019
CO2	Carbon Dioxide
EPA	Environmental Protection Agency
FAMU	Florida Agricultural and Mechanical University
FSU	Florida State University
HOQ	House of Quality
IAQ	Indoor Air Quality
OSHA	Occupational Safety and Health Administration
PM2.5	Particulate matter with a diameter less than 2.5 microns
PM10	Particulate matter with a diameter less than 10 microns
VOC	Volatile Organic Compounds

Chapter One: EML 4551C

1.1 Project Scope

Project Description

Honeywell is sponsoring this project with the goal of improving air quality at indoor hotspots in Doak Campbell stadium. The stadium has issues with indoor air quality in some spaces, such as restrooms, private rooms, and other enclosed areas where people may gather. The motivation of this project is the negative effect that indoor air pollution has on individuals, especially during the present time with viral pathogens and other contaminants.

Key Goals

A key goal for this project is to improve the air quality of public spaces. Being able to decrease or eliminate pathogens and other contaminants is important for a suitable system. Another key goal is to improve user experience and safety, while keeping cost at a relatively low price point. The air quality project is aimed at commercial properties which will accommodate large numbers of people.

Primary Market

The project will be made for Honeywell and is intended to be used by guests at Doak Campbell Stadium; this includes students, faculty, and visitors to the university. Anyone using the restrooms in the stadium will benefit from improved air quality.

Secondary Market

While this project is being designed with visitors to Doak Campbell Stadium in mind, it will also be useful to several other groups of people:

1. Homeowners – According to a report from the Environmental Protection Agency (EPA), it is important to improve air quality in the places where people spend the most time. The report also found that most people spend most their indoor time in their homes and, therefore, it is important that air quality of their home is good (Environmental Protection Agency, 1989).
2. Commercial Buildings – The EPA report found that the indoor space where people spend the second largest amount of time is their workplace (Environmental Protection Agency, 1989). Bad air quality can negatively impact health, so good air quality in commercial buildings is beneficial to both employers and workers .
3. Public Transport Services – Many people, especially those living in cities, rely on public transport to get them to and from work every day. However, it has been documented that the air quality of transit systems, such as the New York City subway, is poor (Moreno & de Miguel, 2018). Improving the air quality of these services will protect the people who use them.
4. Schools – Children and young people are especially vulnerable to the health risks associated with bad air quality (Environmental Protection Agency, 1989). They spend a considerable amount of their indoor time in schools and, therefore, these spaces would benefit from improved air quality.

Project Stakeholders

There is a wide range of stakeholders for this project, the largest being the primary sponsor, Honeywell. Honeywell stands to benefit the most from this project being completed as they could potentially sell it or utilize the design in some larger project. Our points of contact at

Honeywell, Danny White and Lauren Cobb, are both stakeholders as they will be involved in defining expectations and specifications, as well as assisting in obtaining the systems that our project will interface with. The project adviser, Dr. Yahgoobian, is also a stakeholder, as she will be providing assistance with keeping the project on track and utilizing campus resources. Another stakeholder is Dr. McConomy, the professor of mechanical engineering senior design course, who organized the project and assigns the documents that must be completed to effectively complete the project. Finally, owners of enclosed spaces that accommodate lots of people, such as a retail stores or other stadium bathrooms, are stakeholders because they stand to benefit from a system that can reduce the cost of ventilation by dynamically controlling it depending on the occupancy or air quality factors. This is especially relevant within the context of the current pandemic as companies and venues are reopening at limited capacity; proper ventilation in locations where people are more concentrated can make the venue safer.

Assumptions

This project will use existing Honeywell components, such as fans and filters. The components will be modified, reconfigured, and integrated into a new system to meet the goals of the project. We will not use project resources to design new components. The device will not have its own internal power source, an external power source of some kind will be used. The device will be compatible with existing ductwork; no new building infrastructure will need to be designed to accommodate the device. The device will not be self-maintaining. It will require general maintenance work, such as filters being replaced. The device will not be required to differentiate between different kinds of pollutants. It will sense that pollutants are present and eliminate them, but it will not provide feedback to the user on which specific pollutants it has eliminated. Not using a sensor that is able to identify and differentiate specific types of pollutants will aid the timeline of the project because we will not have to spend significant periods of time researching and developing these sensors.

1.2 Customer Needs

The customer statements shown below were gathered during a virtual meeting with our sponsor, Honeywell, on September 21, 2020. Gathering these statements and accurately extracting our sponsor's needs helped us to understand the requirements of the project. We selected our questions before meeting with our sponsor to help define the scope of the project. During the meeting, our sponsor gave us some more details about the project along with giving us an overview of some of the company's existing work.

After the meeting, we translated our sponsor's statements into tangible needs that could be applied to our design. Through this process we found that our sponsor wants a system that will improve the air quality of Doak Campbell Stadium's bathrooms through the removal of contaminants. Furthermore, the customer needs the device to be compatible with their existing products and the ventilation system that is currently in the stadium. The questions, customer answers, and interpreted needs can be seen below in Table 1.

Table 1. *Table showing customer needs.*

Questions	Customer Statement	Interpreted Need
Are there any structural or sizing limitations? e.g. volume, height, length, weight, etc.	It should be able to be attached to a standard vent.	The device will be compatible with a standard ventilation system.
In what environment will the project be used? e.g. home, office, stadium, retail, etc.	The idea is to create a product that can be used at Doak Campbell Stadium in the bathrooms.	The product will be compatible with the ventilation system in Doak Campbell Stadium's bathrooms.
Should it be geared towards reducing contamination or increasing ventilation?	Yes!... the device should achieve both.	The product will reduce air contamination and increase ventilation.
Do you have any existing products or previous research that could be used to help this project?	Similar projects are being done at other stadiums such as the New England Patriots Stadium. We have existing products that will help.	The product will resemble other products that have been installed in other stadiums.
Will our project be used in conjunction with an existing product or will an entirely new system need to be designed?	Since we have products already made, I do not figure that you all will create an entirely new system.	The project will be compatible with existing products.
If it will be used in conjunction with another system, what type of system? Do you have any specific details?	I will give you all more information about our existing products next meeting. We will donate products for you to work with.	The project will be compatible with existing Honeywell products and systems.
What is the nature of the contamination we are aiming to reduce? e.g. viruses, bacteria, fungi, odor, etc.	Originally this was aimed at increasing ventilation to reduce odors but with Coronavirus going around it would be nice to reduce some viruses as well.	The product will reduce odors and presence of pathogens that are in the hotspot area.

Does the project need to be an automatic or a manual system?	It would be great for it to be automatic but if it ends up having to be manual that will work.	The product will be activated automatically.

1.3 Functional Decomposition

The subsequent functional decomposition deconstructs the processes needed to improve the air quality of indoor hotspots. Firstly, the systems, or major functions, needed for the project were identified. Those systems were then broken down to find the minor functions of each system. Using this method to break down the large system into smaller subsystems makes the project more manageable. Moreover, a functional decomposition can encourage innovative design by identifying ways that different subsystems overlap and can potentially be connected. While a functional decomposition does not generate a design for a project, it can be used to reveal the systems necessary in potential designs.

Most of the data used to create this functional decomposition was gathered during a virtual meeting with our sponsor, Honeywell. We asked a series of questions to help define the scope of the project and interpreted our sponsor's responses to find any engineering requirements or specifications. This information can be found in the customer needs table shown in Table 1 in section 1.2. We also made some assumptions about the project on topics where the sponsor was not able to provide any information. The functional decomposition for this project is based on the interpreted needs data from the sponsor and our assumptions.

The functional decomposition was gathered by identifying the physical actions needed to address the sponsor's problem; the air quality of indoor public spaces, such as stadium bathrooms, is often subpar and needs to be improved. The first system we identified was improve air composition. To meet the sponsor's requirement of improving air quality, the composition of the air would need to be enhanced. This relates to removing pollutants in the air such as dust, viruses, and bacteria. The next system identified was ventilate room; the project must ensure that there is airflow around the room. The relationship between these major functions is clear, both are related to the experience of the user. However, we also realized that another system is needed to control these major functions and the control system was added. This system is responsible for sensing when the air needs to be cleaned or circulated and executing the necessary actions to make it happen.

Figure 1 is a functional decomposition flowchart. The boxes on the second tier of the chart, shown in blue, indicate systems in the project. The boxes branching down from the systems, shown in green, indicate functions belonging to each system.

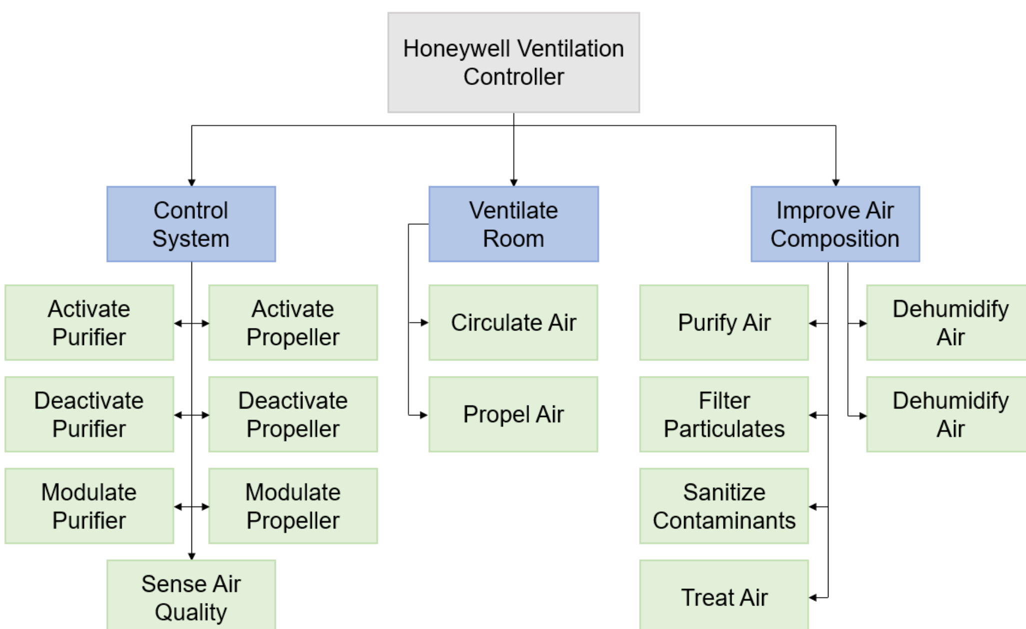

Figure 1. Functional Decomposition Flowchart.

Table 2 is a functional decomposition cross-reference table for our project. The major functions of the system are shown horizontally along the top while the minor functions are shown down the left-hand side vertically. Table 2 was created based on the flowchart shown in Figure 1. An ‘x’ in a box in the table represents a function belonging to a system in the project.

Table 2. *Functional decomposition cross-reference table.*

	Major functions		
Minor functions	Control System	Ventilate Room	Improve Air Composition
Sense Air Quality	x		
Activate Propeller	x		
Deactivate Propeller	x		
Modulate Propeller	x		
Activate Purifier	x		
Deactivate Purifier	x		
Modulate Purifier	x		
Propel Air		x	
Circulate Air		x	x
Purify Air			x
Treat Air			x
Filter Particulates			x
Dehumidify Air			x
Sanitize Contaminants			x
Total	7	2	6

The systems of the device can be ranked by the number of functions which they connect to because a system cannot operate without all its functions. The control system, which is connected to seven functions, is the most important, since every major system relies on the control system to tell it when it should be enabled, and at what level they should be running. The purification system, which is connected to six functions, is the next highest priority system of the device, as it is the system that undergoes the processes by which the air quality will be improved.

The system with the lowest priority is the ventilation system, which is connected to only two functions. This system's only purpose is to circulate air through the purification system, which, while critical to device functionality, is a problem solved by an off the shelf component that likely already exists in locations where the device needs to be installed.

As seen in Table 1, a single function can span multiple systems; the circulate air function spans both the ventilate room and improve air composition systems, thus the air circulation necessary for dehumidification can be accomplished through the same system. Through this, both dehumidification and ventilation can occur without creating a redundant circulation system that only works for one of the two functions. There are also integrations that can be done but are not represented in Figure 1 and Table 1, because they are prerequisites for some functionality, but not necessarily a part of the system. Most notably, the entire purification subsystem requires the ventilation system to propel air through it and circulate the now purified air back into the room. Similarly, the control system activates, deactivates, and modulates the subsystems of both the ventilation and air quality improvement systems.

This functional decomposition has highlighted the physical actions the project needs to carry out to be successful. Using sensors, it will be able to identify when the location is a hotspot. The system will then be activated and will modulate the air in the bathroom. It will ventilate the air by propelling and circulating the contaminated air out of the bathroom. It will also improve the overall air quality by dehumidifying and purifying the air inside the hotspot. The air will be purified by sanitizing and filtering the infected air. Once the system has cleared the air it will automatically deactivate. This product will make going to the bathroom at a stadium a cleaner and overall better experience.

1.4 Project Updates

At this point, the scope of the project was modified, and the location changed from Doak Campbell stadium to the FAMU-FSU College of Engineering. The facilities manager of the college, Donald Hollett, assumed a customer role alongside our sponsor Honeywell. Mr. Hollett has requested that the device be portable and create minimal noise, so it does not distract students. The changes in the project have meant that additional emphasis has been placed on monitoring and measuring air quality alongside improving it. The functional decomposition flowchart for this project has been updated to reflect these changes. Work in later stages of the project is based on this updated flowchart.

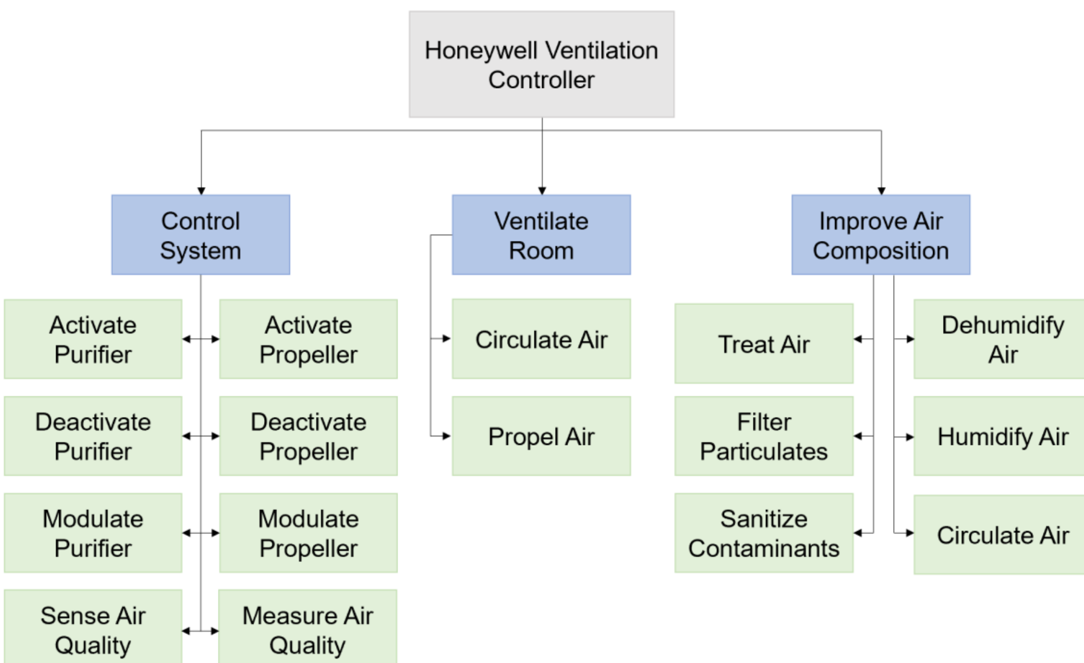

Figure 2. Updated Functional Decomposition Flowchart.

1.5 Target Summary

The following table shows the critical targets and metrics along with their corresponding functions. This information was developed using the interpreted customer needs and functional decomposition shown in earlier sections.

Table 3. *Critical Targets and Metrics.*

Function	**Metric**	**Target**
Sense Air Quality	Concentration range of sensors	Particulate sensors detect between 0.1 μg/m^3 and 1000 μg/m^3 [a] Gas sensors detect between 0 ppm and 250 ppm[b]
Measure Air Quality	Accuracy of sensors	Particulate sensors: ±15%[a] Gas sensors: ±3%[b]
Control Hardware	Reaction time of hardware components	6 seconds[a]
Propel Air	Volumetric flowrate of air leaving device per person in room	40 cfm[c]
Circulate Air	Number of air changes per hour	7[d]
Treat Air	Number of changeable filters needed to clean air	3 filters[e]
Filter Particulates	Minimum diameter of particles the device will filter	0.1 μm[f]
Control Air Humidity	Allowable range of air humidity	40% to 60% humidity[g]
Sanitize Contaminants	Percent of particulates removed from air by device	99%[h]

Note. Data are from (Honeywell, 2019)[a], (Honeywell, 2012)[b], (Environamental Protection Agency , 1990)[c], (Falke, 2016)[d], (Honeywell, n.d.)[e], (Honeywell , n.d.)[f], (M. Jeremiah Matson, 2020)[g], (Sylvane, n.d.)[h].

Critical Targets and Metrics

The critical targets and metrics correspond directly to the functions of the functional decomposition and can be seen in Table 3. The functions and their related targets and metrics include sense and measure air quality, control hardware, propel air, circulate air, treat air, purify air, filter particulates, humidify and dehumidify air, and sanitize contaminants. The full table of functions, targets, and metrics can be seen in Appendix C. The activate purifier, activate propeller, deactivate purifier, deactivate propeller, modulate purifier, and modulate propeller functions seen in the updated functional decomposition, shown in Figure 2, were all found to have the same target and metric, so have been condensed into one function, control hardware, in the critical targets and metrics. Similarly, the functions humidify air and dehumidify air were condensed into the single function control air humidity. The items listed above were chosen to be critical because the device will not be successful if the functions are not able to accomplish the targets that have been set for them. The device portability, device noise, and energy consumption functions, seen in the full catalogue in Appendix C, are not critical because the device will operate without them. However, they are still important to the project and will be considered during the concept generation and selection phases because they satisfy the customer needs of portability and creating minimal noise.

Determination of Targets and Metrics

To determine the critical targets and metrics seen in the table, research was done to see how each of the functions should be carried out and at what specific values they should optimally be performed at. Metrics were selected to quantify each of the functions and numerical values chosen for each of the targets. The targets and metrics associated with the sense air quality, measure air quality, control hardware, treat air, filter air, and sanitize contaminants functions were all derived from existing products. For these functions the products we used for reference were made by our sponsor, Honeywell. This was done to ensure that our project is of high enough quality to be comparable to their existing devices. The target values shown in Table 3 were found in data sheets and devise specifications listed on Honeywell's website.

A Honeywell device, "HPM series Particulate Matter Sensor," features were used to set some of the targets and metrics. Two important features are that the HPM sensor series use a laser based light scattering particle sensor. This allows the sensor to have a concentrated range of 0 $\mu g/m^3$ to 1000 $\mu g/m^3$ and accuracy within 15%. Another device, the "E^3 Point" is a compatible Honeywell device that has a dual gas monitoring and alarm system. The accuracy of this compatible device is ±3% within a range of 10ft and has a concentration range of 0 to 250 ppm. These devices and their associated data sheets were used to set the targets and metrics for the sense air quality and measure air quality function. The data sheets of these devices also provided information regarding the reaction times of Honeywell hardware that was used for the control hardware target value.

The targets and metrics for the treat air, filter particulates, and sanitize contaminants functions were based on filters and air purifiers made by Honeywell. The treat air target relates to the number of filters used in the "True HEPA Whole Room Air Purifier with Allergen Remover". The sanitize contaminants target and metric are based on the air cleaning abilities of

HEPA filters used in this purifier. The filter particulates target value was chosen in relation to another filter made by Honeywell, the “Filter A Universal Carbon Pre-Filter”.

Other targets and metrics were based on industry standards or government suggestions. In a document by the CDC, “Effect of Environmental Conditions on SARS-CoV-2 Stability in Human Nasal Mucus and Sputum,” 40% to 60% humidity in a controlled room was found to help reduce the spread of COVID-19. Therefore, this range was selected as the target for the control air humidity function. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) published its "Standard 62-1989: Ventilation for Acceptable Indoor Air Quality." In this document the standard cfm range person is 15-60ft^3/min. The middle of this range was selected as the target for the propel air function. Finally, the target for the circulate air function was based on the typical number of air changes per hour for office buildings.

Methods of Validation

Methods of validation are needed to ensure that the critical functions meet their corresponding targets and metrics. Some of these functions can be validated using simple inspections and do not require any resources for testing. Among these functions are sense air quality and treat air. To validate that the chosen sensors operate with the ranges specified by the targets shown in Table 3, the data sheets of the sensors can be read, and their operating concentration ranges identified. The treat air function can be tested by counting the number of changeable air filters used in the device and checking that there are three or fewer.

Other functions can be tested and validated using calibrated sensors. These functions include measure air quality, filter particulates, control air humidity, and sanitize contaminates. The measure air quality function can be validated by comparing readings on the particulate and gas sensors used by the device to calibrated sensors and checking that the device's sensors are with the allowed range of accuracy. Similarly, it can be checked whether the humidity is in the allowable range for the control air humidity function by measuring the air humidity using a calibrated hygrometer. The filter particulates and sanitize contaminants functions can be tested and validated using calibrated particle sensors (Texas Instruments , 2016). These devices can measure the size and concentration of particulates. In the case of the sanitize contaminants function, sensors would need to be placed at the opening and exit of the device and their readings compared to ensure the decrease in particulates matches the specified value in the targets. For the filter particulates function, only the sensor at the exit would need to be monitored to check that none of the particulates have diameters larger than 0.1 µm.

To verify the volumetric flow rate of the air, an anemometer will be used to measure air speed and a tape measure used to measure the area of the duct the air is flowing from. The volumetric flowrate of the air can then be calculated based on these measurements and compared to the target values given in Table 3. Furthermore, the total volume of the room can be measured using a tape measure and used in conjunction with the volumetric flowrate to calculate air changes per hour, to verify the circulate air function. Finally, to test the response time of the control hardware function, control signals for each piece of hardware will be sent and a stopwatch will be used to ensure that the reaction timing of the hardware is within acceptable levels.

1.6 Concept Generation

This section contains the medium and high-fidelity ideas created during the concept generation phase of this project. Concepts one through five are medium fidelity ideas, while concepts six to eight are high-fidelity ideas. The full catalogue of 100 concepts can be seen in Appendix D.

Concept 1.

Based on concept 34 in Appendix D - This concept is a mobile air purifier. The air purifier is mounted to a cart so it can be moved to different locations in the FAMU-FSU College of Engineering. The purifier will contain 3 different filters. The first will be a pre-filter, the second filter is to trap particulates with diameters of 10 microns or larger, the third filter has finest mesh to trap even smaller pathogens. A sketch of the concept can be seen in Figure 3.

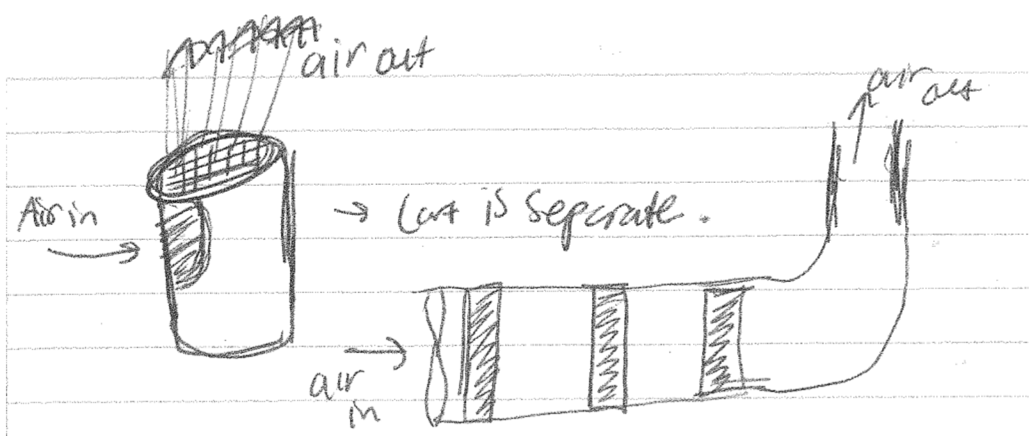

Figure 3. Mobile air purifier.

Concept 2.

Based on concept 36 in Appendix D - This concept is a stationary air purifier that is modelled after a tree. It has multiple inlets for air to enter the purifier and filters placed at each inlet. It will be around 5 ft in height and is designed to purify the air in a large room, such as the atrium in the FAMU-FSU College of Engineering. Since this concept is stationary, it will be powered by mains electricity. A sketch of the concept can be seen in Figure 4.

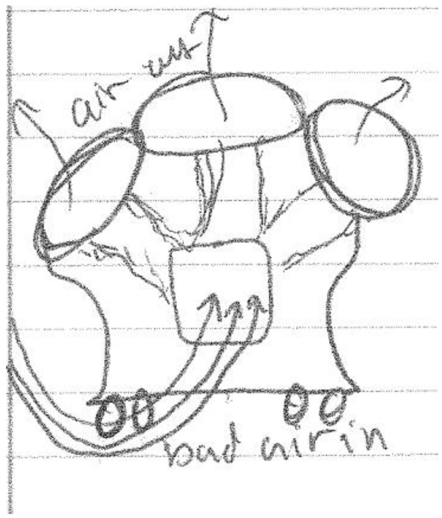

Figure 4. Air Purifier modelled after a tree.

Concept 3.

Based on concept 46 in Appendix D - This concept is an air purifier which attracts air through a rotating outer capsule and then uses the air's velocity to push it through multiple filters. The purifier will contain 3 different filters. The first will be a pre-filter, the second will be a sanitizing filter to kill pathogens, and the third filter will have a very fine mesh to trap small particulates and dead pathogens. A sketch of the concept can be seen in Figure 5.

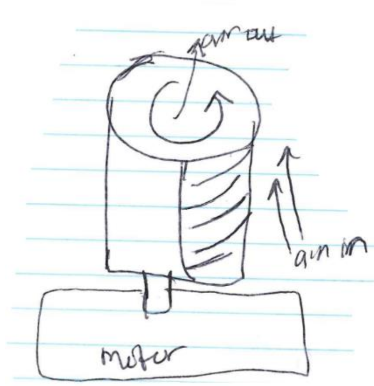

Figure 5. Rotating air purifier.

Concept 4.

Based on concept 47 in Appendix D - This concept is a tabletop air purifier that can moved and placed in different parts of a room. The air quality entering the device will be monitored by a series of sensors. These sensors will send signals to external lights indicating the quality of the air passing through. Green lights will indicate good quality air, yellow lights will indicate moderate air quality, and red lights will indicate bad air quality. The device will be powered by an external battery pack so that it does not need to be placed near an outlet. The purifier will consist of multiple filters to filter particulates and pathogens of different types and sizes. A sketch of the concept can be seen in Figure 6.

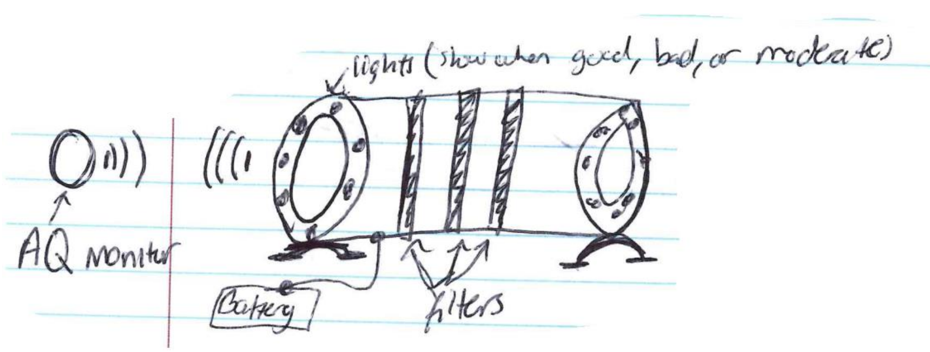

Figure 6. Air purifier with external lights to indicate air quality.

Concept 5.

Based on concept 38 in Appendix D - This concept is an air purifier placed on a cart. This will allow the air purifier to be moved and located in different parts of a room. However, the air purifier will be powered by mains electricity, so the cart will need to be placed near an outlet. The purifier will have a mesh grid top, this is where air will be sucked in. The device will contain multiple filters to trap particulates in addition to a UV light that will be used to kill pathogens and sanitize the air. A sketch of the concept can be seen in Figure 7.

Figure 7. Air purifier with UV light and filters.

Concept 6.

Based on concept 13 in Appendix D - A single cart containing multiple sensors to measure CO_2, particulates, mold spores, and other gasses. The data gathered by the sensors will be sent to a software program which will store and analyze the information. If air is deemed to be subpar quality by the sensors and software, devices to clean the air will be triggered. For air cleaning purposes, the cart will contain a humidifier and air purifier along with fans to promote air circulation. This cart will be mobile, allowing it to be moved to different locations within the

FAMU-FSU College of Engineering to collect data and improve air quality. All devices on the cart will be battery powered. A drawing of this concept can be seen in Figure 8.

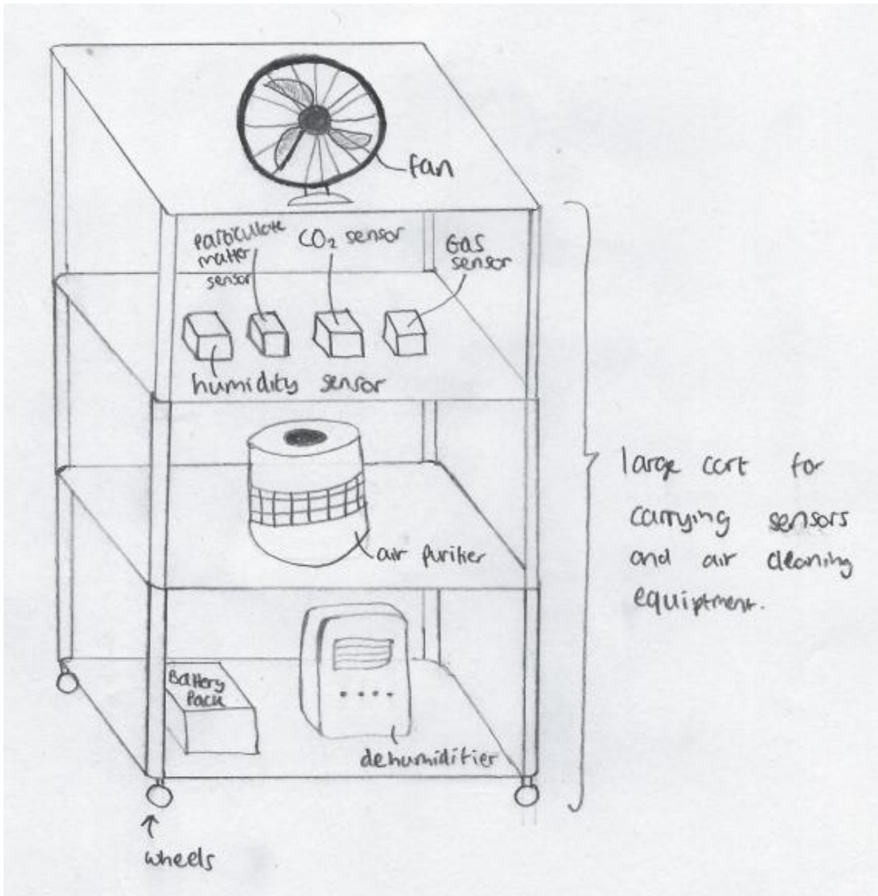

Figure 8. Large, single cart carrying air quality sensors and air cleaning equipment.

Concept 7.

Based on concept 14 in Appendix D - This concept is similar to concept 6 above, however, two carts will be used instead of one. Both carts will be relatively small and similar in size so they will be easy to transport. One cart will be used for sensors to monitor and measure the air quality in the room. It will have devices such as CO_2 sensors, humidity sensors, and a particulate matter sensor. The data gathered from these sensors will be sent to a data processing software. If the software flags an area as having poor air quality the second cart will be transported into the clean air in the room. The cleaning equipment will automatically turn off when the air is found to be good quality. The cleaning cart will contain items such as fans, purifiers, dehumidifiers, air filters, and other sanitizing devices. All devices on both carts will be battery powered. A drawing of this concept can be seen in Figure 9.

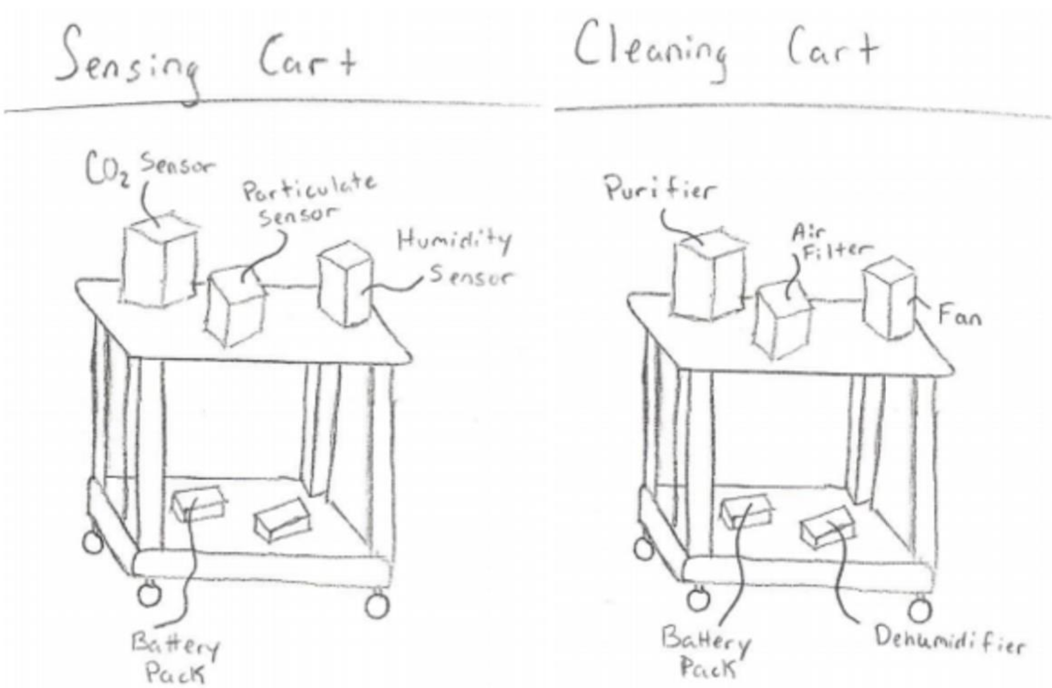

Figure 9. Two carts, one containing air quality sensors, and the other containing sir cleaning equipment.

Concept 8.

Based on concept 48 in Appendix D - Humidity, particulate matter, and CO_2 sensors will be mounted on the walls around the FAMU-FSU College of Engineering. A humidifier, dehumidifier, set of three particulate filters, and a UV sanitization system will be attached to the existing vents, and paired with their nearest sensor. When the sensors detect that the air quality has become poor, the corresponding system in all nearby vents will be enabled to return air quality to optimal levels. Once the air has returned to optimal levels, the cleaning equipment will switch off. A drawing of this concept can be seen in Figure 10.

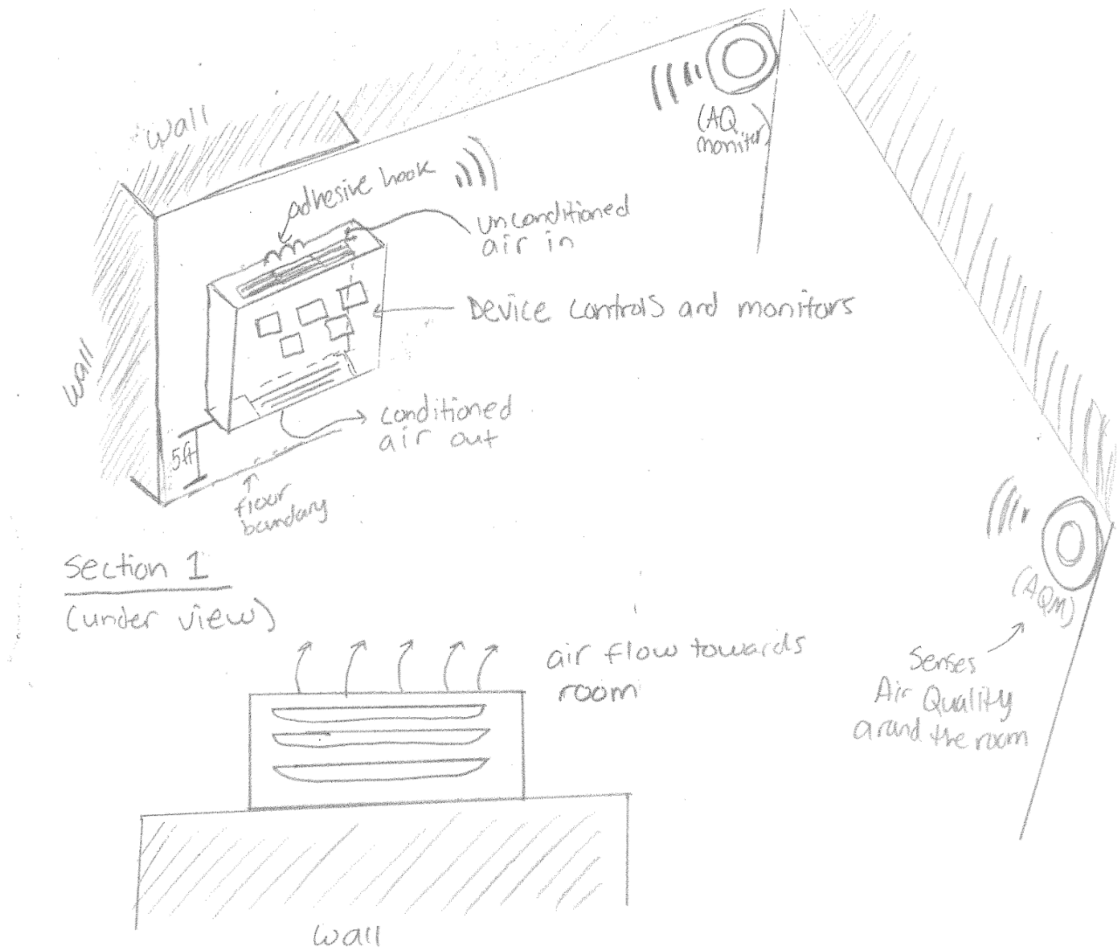

Figure 10. Sensors and cleaning equipment attached to existing infrastructure around room.

1.7 Concept Selection

House of Quality

To convert each of the customer needs to quantifiable parameters that can be used for selecting a design, a House of Quality (HoQ) was created. To construct the HoQ, the importance weight factor for each customer requirement was chosen. The weight factor was chosen through determining the priority of a certain requirement in comparison to the other requirements. These importance weight factors were formulated using Table 4. A box was marked with a one (1) when the characteristic of the row was determined to be more important than the one in the column. The monitor air quality requirement was found to have the highest importance weight factor while the no heat requirement had the lowest.

Table 4. *Comparison of customer requirements to determine importance weight factor.*

	Monitor Air Quality	Portable	No Noise	No Heat	Reduces Contamination	Internal Power Source	Compatiable with Honeywell Products	Doesn't Interfere with Existing Infrastructure	Total
Monitor Air Quality	-	1	1	1	1	1	1	1	**7**
Portable		-	1	1					**2**
No Noise			-	1		1			**2**
No Heat				-					**0**
Reduces Contamination		1	1	1	-	1	1	1	**6**
Internal Power Source		1		1		-			**2**
Compatiable with Honeywell Products		1	1	1		1	-		**4**
Doesn't Interfere with Existing Infrastructure		1	1	1		1	1	-	**5**

The engineering characteristics chosen for this project during the targets and metrics phase were then compared to the customer requirements in the HoQ. Each engineering characteristic was given a value ranging from 0 to 9, depending on how heavily that characteristic impacts the customer requirement. The HoQ pictured in Table 5 shows the relationship between the engineering characteristics and the customer requirements.

Table 5. *House of Quality*.

		Engineering Characteristics							
Improvement		↑		↑	↓	↓	↓	↓	↓
Units		µg/m3		ft3/min	dBA	Watts	ft3	sec	µm
Customer Requirements	**Importance Weight Factor**	**Concentration Range of Sensors**	**Accuracy of Sensors**	**Volumetric Flowrate**	**Noise Level**	**Daily Energy Consumption**	**Volume of Device**	**Reaction Time of Hardware Components**	**Minimum Diameter of Particles the Device Will Filter**
Monitor Air Quality	**7**	9	9					3	
Portable	**2**					1	9		
No Noise	**2**			1	9				
No Heat	**0**								
Reduces Contamination	**6**	3	9	9				3	9
Internal Power Source	**2**					3	1		
Compatiable with Honeywell Products	**4**	1	1						
Doesn't Interfere with Existing Infrastructure	**5**						1		
Raw Score (406)		85	121	56	18	8	25	39	54
Relative Weight %		20.94	29.80	13.79	4.43	1.97	6.16	9.61	13.30
Rank Order		2	1	3	7	8	6	5	4

The values in Table 5 were then used to determine weights for each engineering characteristic which allowed the importance of the characteristics to be ranked. The accuracy of the sensors was the highest ranked characteristic. It is the most important because it heavily impacts the ability of the device to effectively monitor air quality and reduce contamination, which were the two most important needs from Table 4. The least important characteristic is the daily energy consumption of the device, since it only slightly affects portability and the usage of an internal power source, two relatively unimportant customer requirements.

We then compared the important characteristics determined in Table 5 to the five medium and three high fidelity designs described in section 1.6 of this evidence manual. The types of filters and fans used in each concept are very similar, so all designs were thought to perform the same in relation to the volumetric flowrate, noise level, volume of device, reaction time of hardware, and minimum diameter of filterable particles characteristics. Concepts 13, 14, and 47, 48 all possess air quality sensors so can fulfil the needs of the two most highly ranked engineering characteristics, concentration range of sensors and accuracy of sensors. Therefore, at this stage in the concept selection process, these four design concepts were the frontrunners.

Pugh Chart

A Pugh chart was then created for the medium and high-fidelity concepts that were generated. Each concept was compared against a datum concept to determine whether the concept performed better, worse, or the same for each characteristic. Table 6 shows our eight medium and high-fidelity concepts being compared against a standard air purifier as the datum.

Using Table 6, Concepts 36, 38, 46, and 47 were be eliminated because of their low performance relative to other concepts. These concepts had the highest number of minuses compared to a relatively small number of plusses. A second Pugh chart was created using the top four concepts, 13, 14, 43, and 48. Concept 34 was chosen as the datum for this Pugh chart because it performed moderately well in Table 6. The second Pugh chart can be seen in Table 7.

Table 6. *Initial Pugh chart using a standard air purifier as the datum.*

Pugh Chart									
Engineering Characterisitcs	Datum: Air Purifier	Concept 13: Single mobile cart	Concept 14: double mobile cart	Concept 34: Air purifier on cart	Concept 36: Stationary air purifier	Concept 38: Air purifier with UV cleaning	Concept 46: rotating air furifier	Concept 47: Light-up air purifier	Concept 48: Wall mounted sensors
ability to circulate air	Datum	+	S	+	+	S	S	-	+
ability to purify air		+	+	S	+	+	+	+	S
ability to filter particulates		+	+	+	+	S	S	+	S
ability to humidify and dehumidify air		+	+	+	+	-	-	-	+
utilizes control systems		+	+	+	-	-	-	S	+
portable		S	+	+	-	-	-	+	-
utilizes proprietary power source		S	S	S	-	-	-	S	+
utilizes multiple sensors		S	S	-	-	-	-	+	S
Plusses		5	5	5	4	1	1	4	4
Minuses		0	0	1	4	5	5	2	1
Satisfactory		3	3	2	0	2	2	2	3

Table 7. *Secondary Pugh chart with concept 34 as the datum.*

Pugh Chart				
Engineering Characterisitcs	Concept 34: Air purifier on cart	Concept 13: Single mobile cart	Concept 14: double mobile cart	Concept 48: wall mounted sensors
Ability to circulate air	Datum	+	S	S
ability to purify air		+	+	+
ability to filter particulates		+	+	+
ability to humidify and dehumidify air		+	+	+
utilizes control systems		S	S	+
utilizes mobility		S	+	-
utilizes proprietary power source		S	S	-
utilizes multiple sensors		S	S	S
Plusses		4	4	4
Minuses		0	0	2
Satisfactory		4	4	2

Concept 48 was the worst performing design in the second Pugh chart, as shown in Table 7, leading to its elimination. Concepts 13 and 14 tied as the best designs with four plusses and no minuses. They performed the same as or better than concept 34 in all categories, which led us to eliminate concept 34 as a prospective design. Concepts 13 and 14 performed equally well in both the HoQ and Pugh chart selection techniques, leading us to use the Analytical Hierarchy Process (AHP) to make the final decision.

Analytical Hierarchy Process (AHP)

The functions determined through the updated functional decomposition, shown in section 1.4 of this manual, were used to create the AHP. The full catalogue of tables generated during this process are shown in Appendix E. The criteria weights found in Table 8, were used to determine the importance of each function.

Table 8. *Normalized Criteria Comparison Matrix.*

Development of Candidate Set of Criteria Weights {W}													
Normalized Criteria Comparison Matrix [NormC]													
Engineering Characteristics	**Portability**	**Sense air Quality**	**Propeller Activation**	**Propeller Modulation**	**Purifier Activation**	**Purifier Modulation**	**Air Propulsion**	**Air Purification**	**Air Treatment**	**Filter Particulates**	**Humidify**	**Sanitize**	**Criteria Weight {W}**
Portability	0.0183	0.0564	0.0037	0.0027	0.0041	0.0037	0.0092	0.0140	0.0284	0.0606	0.0171	0.1554	0.0311
Sense air Quality	0.0061	0.0188	0.0037	0.0038	0.0058	0.0052	0.0092	0.0100	0.0203	0.0433	0.0284	0.2591	0.0345
Propeller Activation	0.1280	0.0940	0.0258	0.1337	0.0288	0.0782	0.0153	0.0100	0.0203	0.0433	0.0171	0.0074	0.0502
Propeller Modulation	0.1280	0.0940	0.0037	0.0191	0.0041	0.0261	0.0153	0.0100	0.0203	0.0433	0.0171	0.0074	0.0324
Purifier Activation	0.1280	0.0940	0.0258	0.1337	0.0288	0.1304	0.0153	0.0100	0.0284	0.0606	0.0171	0.0074	0.0566
Purifier Modulation	0.1280	0.0940	0.0086	0.0191	0.0058	0.0261	0.0153	0.0140	0.0284	0.0606	0.0171	0.0104	0.0356
Air Propulsion	0.0915	0.0940	0.0774	0.0573	0.0865	0.0782	0.0460	0.0233	0.0474	0.0606	0.0171	0.0173	0.0580
Air Purification	0.0915	0.1316	0.1806	0.1337	0.2018	0.1304	0.1381	0.0699	0.1422	0.1010	0.0171	0.0173	0.1129
Air Treatment	0.0915	0.1316	0.1806	0.1337	0.1441	0.1304	0.1381	0.0699	0.1422	0.1010	0.2558	0.1554	0.1395
Filter Particulates	0.0915	0.1316	0.1806	0.1337	0.1441	0.1304	0.2301	0.2098	0.4267	0.3030	0.4263	0.2591	0.2222
Humidify	0.0915	0.0564	0.1290	0.0955	0.1441	0.1304	0.2301	0.3497	0.0474	0.0606	0.0853	0.0518	0.1226
Sanitize	0.0061	0.0038	0.1806	0.1337	0.2018	0.1304	0.1381	0.2098	0.0474	0.0606	0.0853	0.0518	0.1041
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The criteria weight shown in Table 8 provides a different perspective on what is important for device functionality compared to the HoQ discussed earlier. The criteria weights of functions related to cleaning air had higher criteria weights than other functions. The table shows that filtering particulates is the most important characteristic, whilst portability is the least important. This was found because the device will not be able to fulfil the project brief of improving air quality if it cannot clean air. However, it can fulfil this brief if it does not possess other characteristics, such as portability.

Concept 14 utilizes two carts, one for sensors to monitor air quality, and another containing equipment to clean the air if the sensors determine it to be bad quality. Concept 13 is comprised of a single cart containing both sensing and cleaning equipment. The two-cart model used in design 14 provides space for more cleaning equipment to mounted to the cart. The ability to use more equipment and have greater flexibility of where it is placed on the cart is an advantage over the one-cart model. Therefore, Concept 14 is better equipped to fulfil the design requirements deemed important in the AHP.

Final Selection

From the Pugh chart in Table 7, all concepts but Concept 13: Single Mobile Cart and Concept 14: Double Mobile Cart were eliminated. The other high-fidelity design, Concept 48: Wall Mounted Sensors, can further be eliminated since it is completely fixed in place, which is directly in opposition to the customer need of portability. The fixed nature of this design also prevents us from moving the devices to hotspots where air quality is a particular risk.

Concepts 13 and 14 are quite similar, both placing the cleaning and sensing equipment on battery powered carts that can be moved around the FAMU-FSU College of Engineering, the primary difference being that Concept 14 places the sensing equipment on one cart to be used to check air quality, only bringing in the second cart with cleaning equipment when the air quality is poor. Concept 14 allows for more flexibility in both sensing and cleansing equipment as their size constraints no longer affect each other. For this reason, Concept 14 was ultimately chosen for this project.

1.8 Spring Project Plan

Table 9. *Spring Project plan showing required tasks and the days they should be done.*

Week #	Dates	College Events	Senior Design	Project
1	Jan. 6 – 8			
2	Jan. 11 – 15	Apply for Graduation	Staff Meeting 1	Finalize ideas with Honeywell
3	Jan. 18 – 22	Jan. 18 Martin Luther King Jr. Day, No Classes	Design Review 4	
4	Jan. 25 – 29		Abstract	
5	Feb. 1 – 5		Abstract Resubmit	Research equipment that we will receive
6	Feb. 8 – 12		Staff Meeting 2	Discuss with Honeywell Jacksonville team
7	Feb. 15 – 19		Design Review 5	
8	Feb. 22 – 26		Conference Paper Identification	
9	Mar. 1 – 5		Poster	Confirm Final BOM with Honeywell
10	Mar. 8 – 12		Staff Meeting 3	
11	Mar. 15 – 19		Operation Manual	Collect some materials and start assembly
12	Mar. 22 – 26		Web Page Development	Run tests
13	Mar. 29 – Apr. 2		Design Review 6	Process data
14	Apr. 5 – 9	Engineering Design Day	Design Day Presentation	Design Day
15	Apr. 12 – 16	Last Week of Classes	Final Report/Web Page Final	Project complete
16	Apr. 19 – 23	Final Exam Week/Graduation		

Once we return from Winter break, we confirm the project ideas with our contacts from Honeywell so that they can process the orders and have the necessary equipment sent to us. Before the equipment arrives, we will research information about the equipment so that we are familiar with it when it gets to us. When the supplies make it to us, we will begin assembly. After everything is assembled, we will run tests in the senior design lab and room B135 of the College of Engineering building. We will then process and present of data to complete our project. Throughout the whole semester we will be in contact with representatives from Honeywell so that we can keep each other updated on progress that is being made.

Chapter Two: EML 4552C

2.1 Restated Project Definition and Scope

Project Description

Honeywell is sponsoring this project with the goal of improving air quality at indoor hotspots in the FAMU-FSU College of Engineering . The objective of the project is to measure the air quality in the college and modify the air based on these findings to promote a healthy building environment. The motivation of this project is the negative effect that indoor air pollution has on individuals, especially during the present time with viral pathogens and other contaminants.

Key Goals

A key goal for this project is to improve the air quality of public spaces. Being able to decrease or eliminate pathogens and other contaminants is important for a suitable system. Another key goal is to improve user experience and safety, while keeping the running cost of the project at a relatively low price point. The air quality project is aimed at commercial properties which will accommodate large numbers of people.

Primary Market

The project will be made for Honeywell and is intended to be used by guests at the FAMU_FSU College of Engineering; this includes students, faculty, and visitors to the university.

Secondary Market

While this project is being designed with users of the FAMU-FSU College of Engineering in mind, it will also be useful to several other groups of people:

5. Homeowners – According to a report from the Environmental Protection Agency (EPA), it is important to improve air quality in the places where people spend the most time. The report also found that most people spend most their indoor time in their homes and, therefore, it is important that air quality of their home is good (Environmental Protection Agency, 1989).
6. Commercial Buildings – The EPA report found that the indoor space where people spend the second largest amount of time is their workplace (Environmental Protection Agency, 1989). Bad air quality can negatively impact health, so good air quality in commercial buildings is beneficial to both employers and workers .
7. Public Transport Services – Many people, especially those living in cities, rely on public transport to get them to and from work every day. However, it has been documented that the air quality of transit systems, such as the New York City subway, is poor (Moreno & de Miguel, 2018). Improving the air quality of these services will protect the people who use them.
8. Schools – Children and young people are especially vulnerable to the health risks associated with bad air quality (Environmental Protection Agency, 1989). They spend a considerable amount of their indoor time in schools and, therefore, these spaces would benefit from improved air quality.

Project Stakeholders

There is a wide range of stakeholders for this project, the largest being the primary sponsor, Honeywell. Honeywell stands to benefit the most from this project being completed as they could potentially sell it or utilize the design in some larger project. Our points of contact at

Honeywell, Danny White and Danny Mims, are both stakeholders as they will be involved in defining expectations and specifications, as well as assisting in obtaining the systems that our project will interface with. The project adviser, Dr. Yahgoobian, is also a stakeholder, as she will be providing assistance with keeping the project on track and utilizing campus resources. Another stakeholder is Dr. McConomy, the professor of mechanical engineering senior design course, who organized the project and assigns the documents that must be completed to effectively complete the project. Finally, the facilities manager of the FAMU-FSU College of Engineering, Donald Hollett, is also a stakeholder because he will oversee the day-to-day running of the project once it has been put in place. This is especially relevant within the context of the current pandemic as schools and universities are returning to face-to-face learning at limited capacity; proper ventilation in locations where people are more concentrated can make the venue safer.

Assumptions

This project will use existing Honeywell components, such as fans and filters. The components will be modified, reconfigured, and integrated into a new system to meet the goals of the project. We will not use project resources to design new components. The device will not have its own internal power source, an external power source of some kind will be used. The device will be compatible with existing ductwork; no new building infrastructure will need to be designed to accommodate the device. The device will not be self-maintaining. It will require general maintenance work, such as filters being replaced. The device will not be required to differentiate between different kinds of pollutants. It will sense that pollutants are present and eliminate them, but it will not provide feedback to the user on which specific pollutants it has eliminated. Not using a sensor that is able to identify and differentiate specific types of pollutants will aid the timeline of the project because we will not have to spend significant periods of time researching and developing these sensors.

2.2 Operation Manual

Note: This operation manual was created before parts had arrived or assembly was possible. Content is subject to change.

Project Overview

The primary goal of this project is to measure and modify air quality in the FAMU-FSU College of Engineering to promote a healthy building environment. This project is motivated by the ongoing COVID-19 pandemic. The virus SARS-CoV-2 causes the disease COVID-19 and is carried through the air in respiratory droplets. Maintaining high air quality is key in preventing the spread of the disease. Our project will utilize a pair of carts to measure and modify air quality. Each cart will contain a set of air quality sensing devices along with an air purifier. The sensing devices will measure certain aspects of air quality and feed the measured data to a controller. The controller is responsible for recording and processing the data, so the data can be used to provide clear, meaningful statistics back to the user. When air quality is identified to be unsatisfactory by the sensing devices, the air purifier can be used to improve it. The sensing devices will continue to monitor air quality while the purifier is running, allowing the user to see when air quality has reached satisfactory levels. One cart is intended for short term use. It should be placed in spaces for only a couple hours at a time to gather data with a high sampling rate. The second cart is intended for long-term use. It should be kept in the same location for longer periods of time to track how air quality changes.

Module Description

The following section contains descriptions of all equipment that will be used for this project. Photographs of each piece of equipment has been provided where available.

Global Industrial™ Mobile Security LCD Computer Workstation: The cart that will house sensing and cleaning equipment and move it around the college. This cart contains a lockable cabinet (Global Industrial , n.d.).

Figure 11. Portable Cart.

P3 International Kill A Watt EZ Energy Monitor: Plug-in energy monitor that will be used to track the cost of energy usage for this project (P3 International , n.d.).

Figure 12. Energy Monitor.

APC UPS - 425 VA 6 Plug: Battery backup and surge protector to be used for powering equipment on short term testing cart (APC, n.d.).

Figure 13. Power Supply and Surge Protector.

JACE 8000 Controller: The controller that will be used to record and process measured data from air quality sensing equipment (Tridium, n.d.).

Figure 14. JACE 8000 Controller.

JACE 8000 Wall Adapter: The adapter that will be used to provide power to the controller (Honeywell, n.d.). No photograph of this device is available.

C7355A Room IAQ Monitor: The indoor air quality monitor that will be used to measure gas and humidity levels (Honeywell).

Figure 15. Gas and Humidity Monitor.

Air Quality Meter PCE-RCM 16: The sensing device that will be used to measure particulate matter in the air (PCE , n.d.).

Figure 16. Air Quality Meter.

Honeywell DUAL TEC PIR Motion Detector: The sensor that will be used to detect whether there are people in rooms where air quality is being tested (Honeywell, n.d.).

Figure 17. Motion Detector.

Kele 120 VAC / 24 VAC Enclosed Class 2 100 VA – FDI: DC Power supply used to power sensors during testing (Kele, n.d.).

Figure 18. Power Supply.

Honeywell Bluetooth Smart True HEPA Purifier: The air purifier used to improve air quality when it is deemed to be unsatisfactory (Honeywell, n.d.).

Figure 19. Air Purifier.

Assembly:

All individual pieces of equipment should be assembled and operated according to manufacturer's guidelines. Manuals for each piece of equipment have been submitted alongside this operation manual where available. For more information on the EZ Energy Monitor refer to "Kill A Watt™ EZ." For the APC UPS refer to "User Manual Back-UPS™." For the Room IAQ Monitor refer to "Air Quality Monitor Quick Start_." For the Air Quality Meter refer to "user manual air quality meter PCE-RCM 16." For the Kele Power supply refer to "PSB / PSC Series Installation Instructions." For the HEPA Purifier refer to "The Doctor's Choice True Hepa Air Purifier with Bluetooth® Smart Technology". Equipment should be wired together according to the wiring chart below. Each cart will hold the identical sets of equipment and the equipment on each cart should be wired the same way. All sensors, air purifiers, and controllers should be attached to power supplies. The Air Quality Meter should be attached to the Kele DC power supply. The sensors should also be connected to the controller using the appropriate communication cable according to the device manuals.

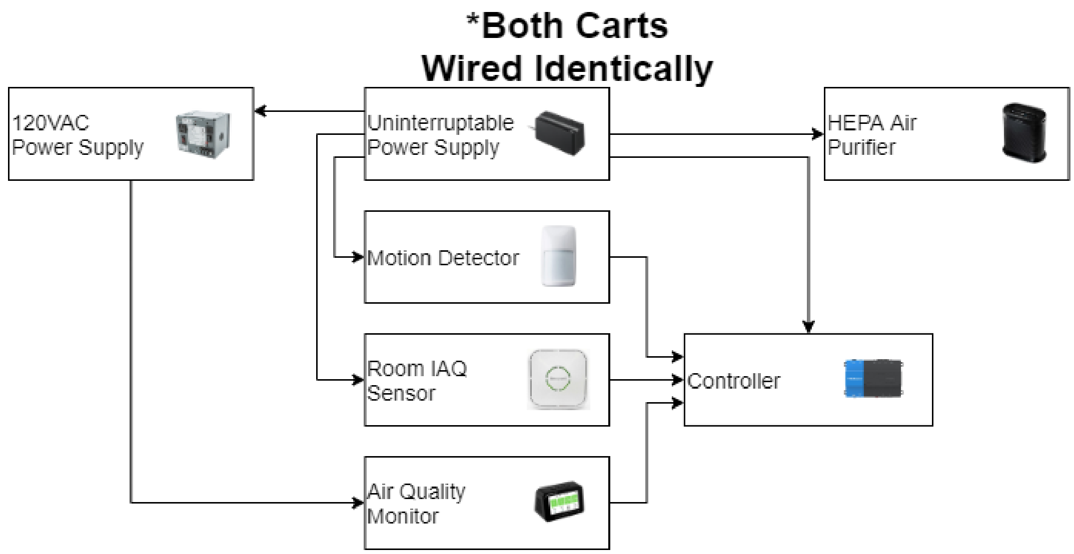

Figure 20. Wiring chart for equipment in carts.

Once the devices have been wired together, they can be loaded onto the carts. The sensing devices can be stored in the cart's lockable cabinets when not in use. When they are needed, the sensing devices can be arranged on top on the carts in a way that best suits the tests being run. Similarly, when not in use, the air purifier can be stored in the cabinet of a cart. When needed, it can be removed from the cabinet and placed in the user's desired location around the room.

Operation:

1. Connect all sensing devices to power sources and switch them on. Only devices intended for short term use should be connected to the APC UPS - 425 VA 6 Plug to avoid creating a fire hazard.
2. Connect JACE controller to computer and open data collection and processing program. Check that all sensing devices are connected to the controller.
3. Begin data collection from sensing devices.

4. If air quality is deemed to be unsatisfactory by the data collection and processing program, use air purifier to clean air. Place air purifier in desired location and connect to a power supply. Once the air purifier has been positioned, switch it on.
5. Continue use of air purifier until data collection and processing program has determined that the air quality has been raised to satisfactory levels. Once this has occurred, the air purifier can be switched off, unplugged, and returned to storage.
6. Once air quality testing has been completed, the sensing devices and controller should be powered off and unplugged from their power sources. When this has been done they can be returned to their storge locations.

Trouble Shooting

1. If the sensing devices will not switch on, check that they have been plugged into power sources.
2. If the controller will not register the cleaning devices, check their wiring. The wires connecting the sensing devices and controller may have come lose or become damaged. If the wires are damaged, they should be replaced.
3. If the air purifier will not switch on, check that it is connected to a power supply.
4. If the air quality does not improve after the air purifier has been running, check the filters of the air purifier. They may have become clogged and need to be replaced.
5. If devices connected to the APC UPS - 425 VA 6 Plug are not switching on or lose power while in use, the power station may need to be charged. Pause testing until the power station has been recharged and then reconnect devices and resume testing.

2.3 Results and Discussion

The controllers used in this project automatically generate graphs using the data from the Honeywell Indoor Air Quality Sensor and compiles them into a web interface pictured in Figure 21. This web interface can display up to a month's worth of the temperature, relative humidity (RH), carbon dioxide (CO2), total volatile organic compounds (TVOC), and particulate matter levels (PM2.5, PM10) data. These graphics can be used to easily make determinations about the air quality, as well as allowing for live tracking of the purifier's effects.

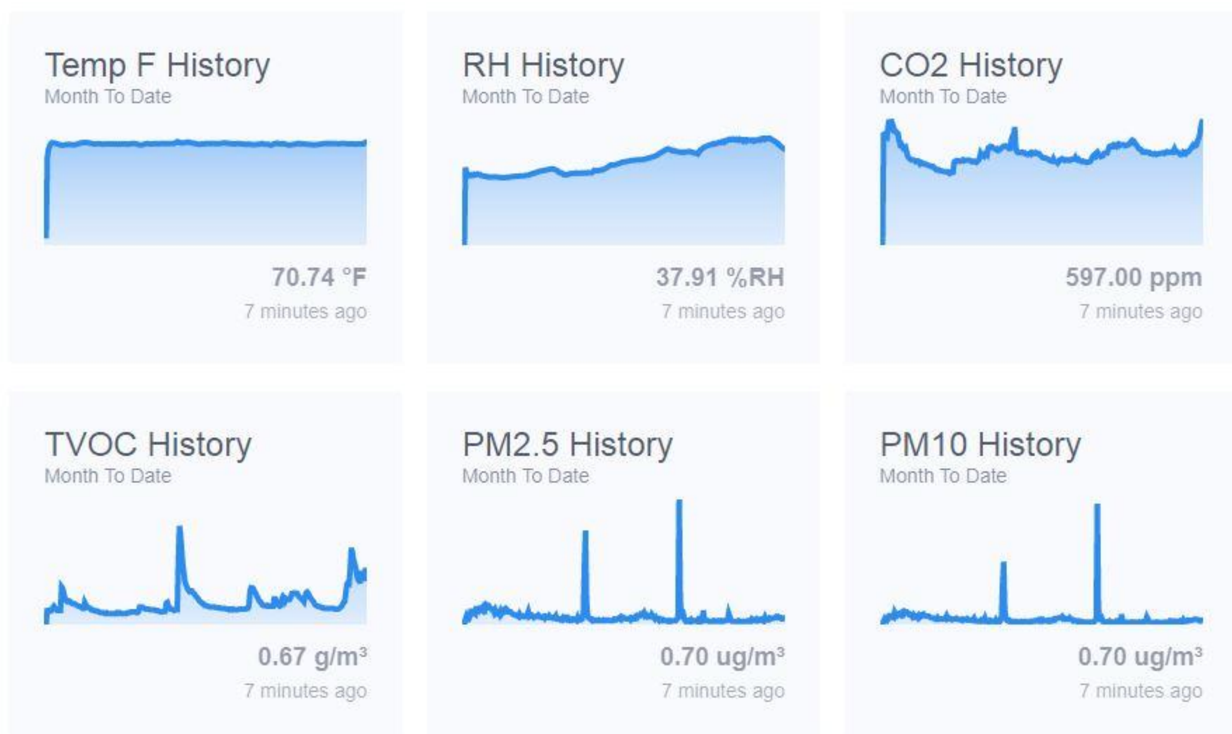

Figure 21. Web display from JACE controller picturing data sampled at 15 minutes per sample.

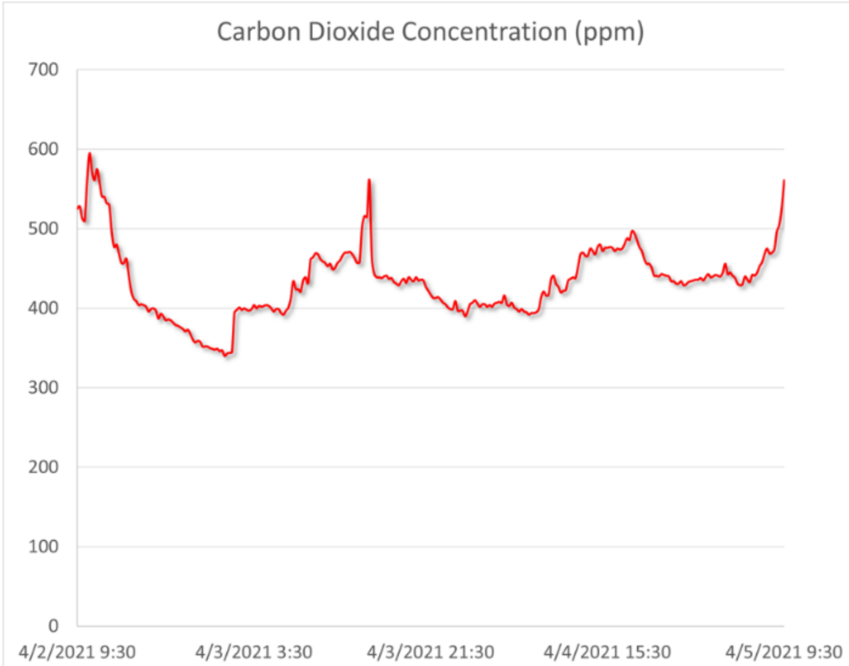

Figure 22. CO_2 concentration in senior design lab with a sampling rate of 15 min.

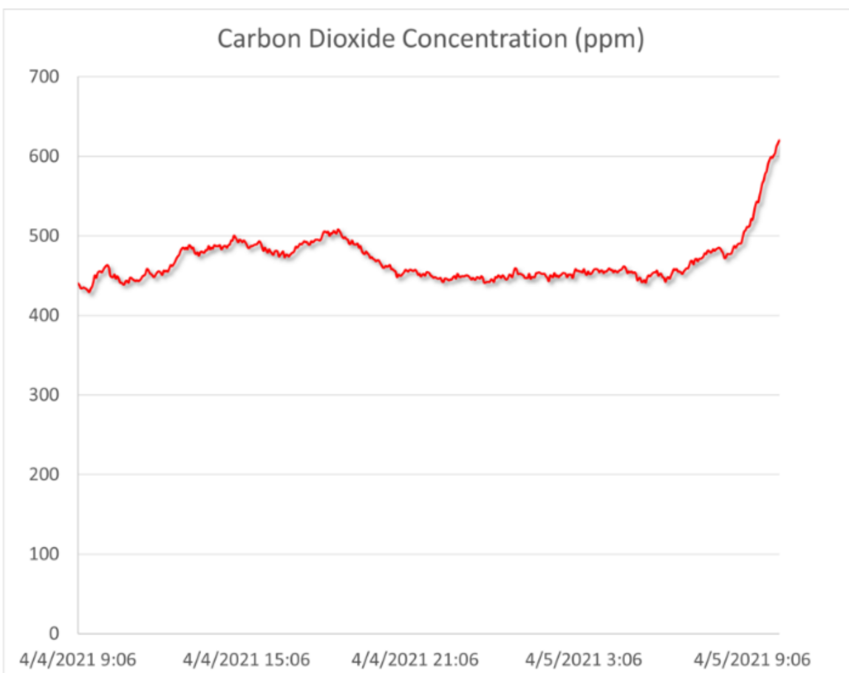

Figure 23. CO_2 concentration in senior design lab with a sampling rate of 3 min.

The graphs in Figures 22 and 23 show data gathered from the controller when the sampling period of the sensors was set to 15 minutes and 3 minutes, respectively. The sampling period of the controller can be adjusted down to one sample per minute. However, the storage space of the controller is limited, and at fewer than three minutes per sample, the controller cannot store more than a day's worth of data. This can be seen in Figure 23, when a sampling period of three minutes was used, all data from before the most recent day was lost. The entire testing period of data was preserved on the other controller which sampled with a period of fifteen minutes, as seen in Figure 22.

To observe the effects of 3D printing on the air quality within the room, the presence of volatile organic compounds within the senior lab was monitored over the course of an hour, both when 3D printers were running, and while they were not. The results of these tests can be seen in Figures 24 and 25. In Figure 24, when there is no 3D printing, the TVOC level stays fairly constant throughout the testing period. In contrast, Figure 25 shows a near three-fold increase in the presence of volatile organic compounds shortly after 3D printing begins at 10:50 am. Air with TVOC levels above 3 mg/m^3 can be considered poor (Honeywell, n.d.). The TVOC levels shown in our gathered data are within an acceptable range (Honeywell, n.d.). However, if the ventilation system within the senior design lab were to fail, the 3D printers could pose a risk to the air quality.

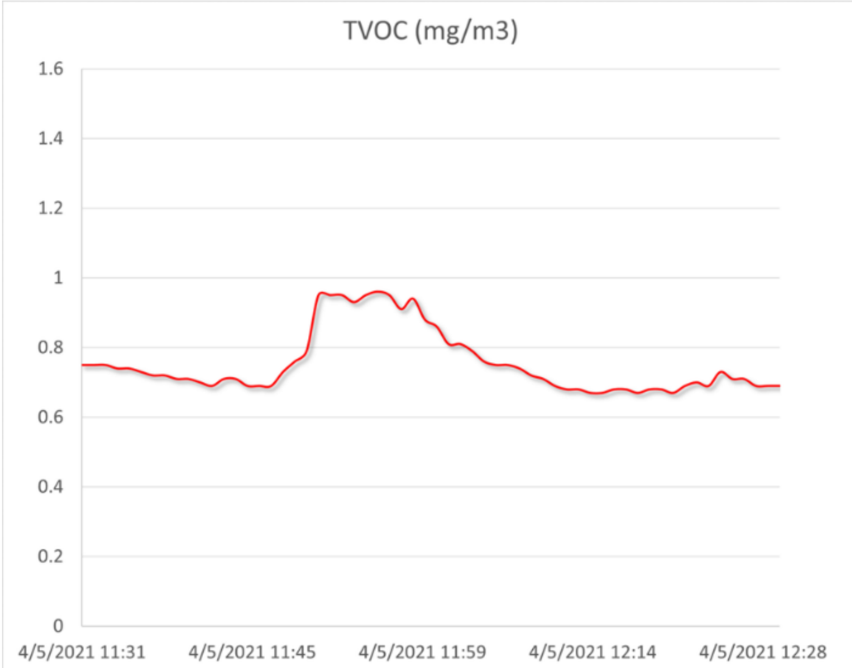

Figure 24. TVOC concentration in senior design lab with 3D printers off.

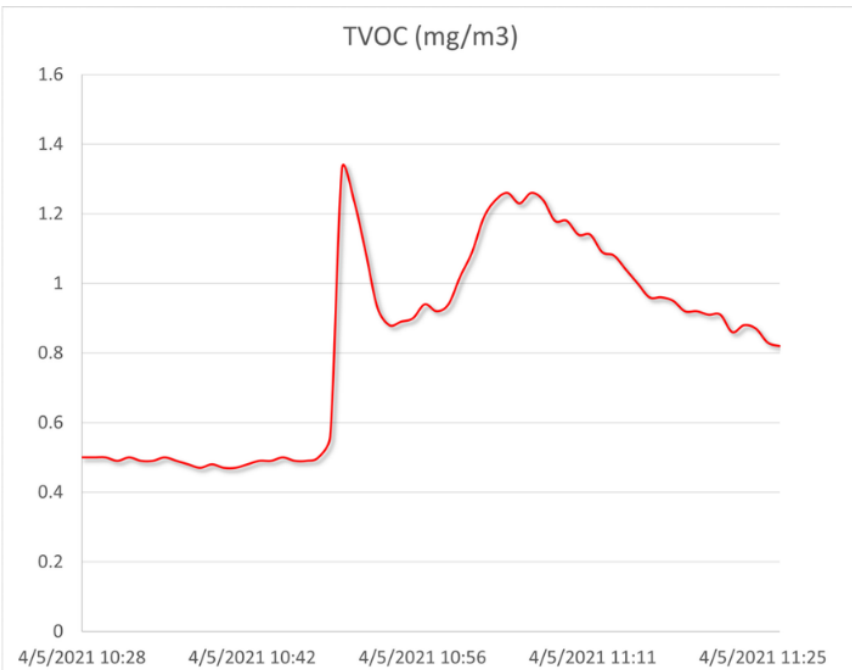

Figure 25. TVOC concentration in senior design lab with 3D printers on.

To examine the effects of running the HEPA Air Purifier intermittently, particulate matter concentration was monitored over the course of an hour with the purifier running both constantly and intermittently. During intermittent testing, the purifier was turned on for ten minutes, then left off for ten minutes. The particulate matter concentrations for each hour are shown in Figures 26 and 27. Both graphs exhibit a downward trend, showing that the purifier can be used constantly or intermittently to improve air quality. However, more testing over a longer period is necessary to determine the potential cost savings introduced by running the purifier intermittently.

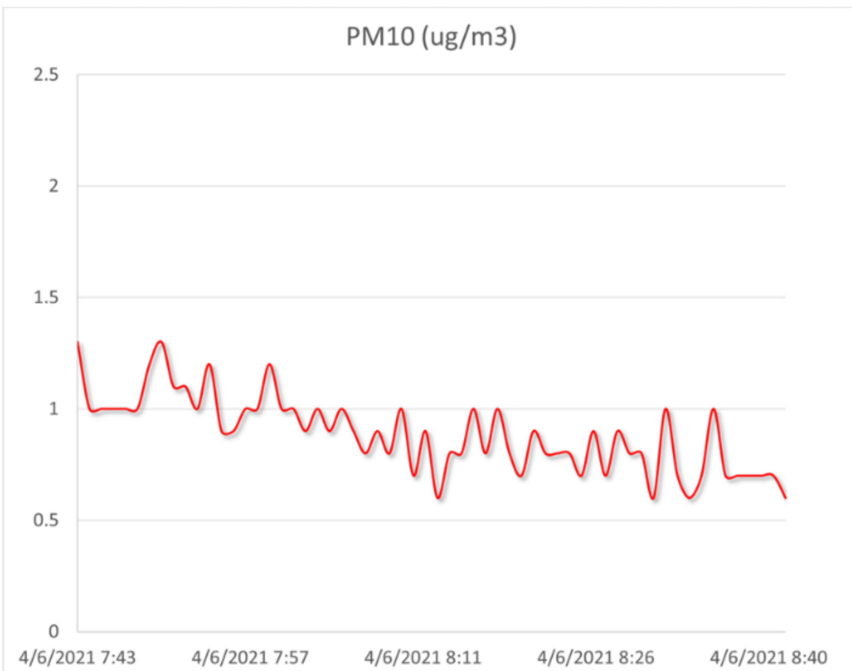

Figure 26: Particulate matter concentration in senior design lab when purifier was run constantly.

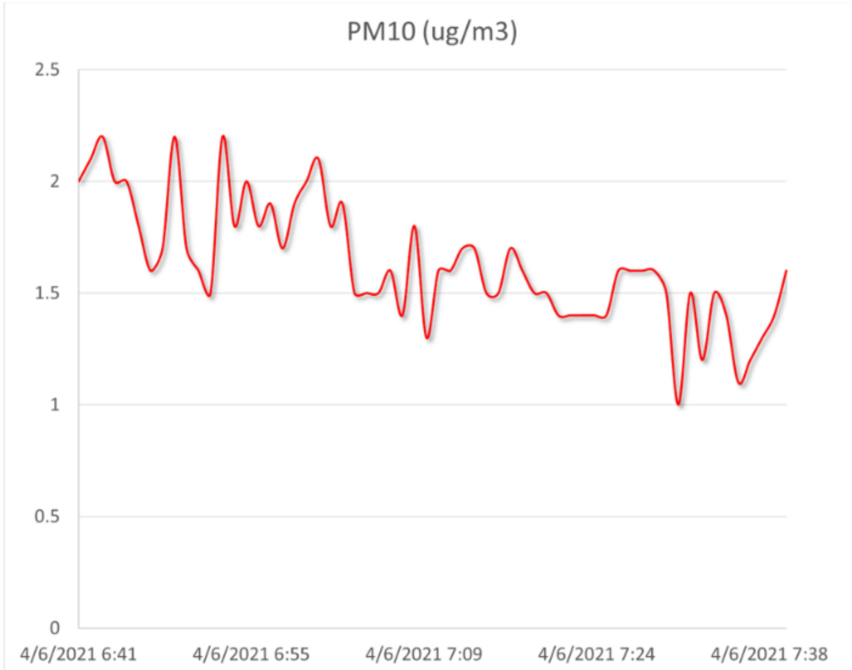

Figure 27: Particulate matter concentration in senior design lab when purifier was run intermittently.

The variety of things that the sensors measure allows for determinations to be made about many potential causes for air quality degradation. The carts can be deployed for both long and short-term testing in multiple areas in many situations, allowing an in-depth profile of the air quality to be established anywhere in a building.

2.3 Conclusions

We were able to meet our goal of measuring and modifying air quality to promote a healthy building environment. Our customer's and sponsor's needs were successfully implemented through the development of a mobile sensing and cleaning cart that was capable of being placed in active classrooms without interrupting students or professors. Computational Fluid Dynamics (CFD) simulations were completed to help locate equipment in rooms for effective cleaning. After seven days of testing in the senior design laboratory, the gathered results show that the cart can improve indoor air quality. The measuring equipment could successfully track degradations in air quality due to factors such as 3D printing. The collected data shows that the air quality improved once the air purifier was turned on, filtering out particulates and other substances. The tests also found evidence that the purifier can be used intermittently to clean air in a more cost-effective and energy-saving manner. While further data should be gathered in different locations to confirm the results found in the senior design lab, the preliminary results suggest the project was a success.

2.4 Future Work

Future work will consist of completing long and short-term tests in the senior design lab. The constant vs intermittent purification test will also be continued for a longer period to get more data on the air quality and energy saving potentials. Tests will then be run in other labs, classrooms, and offices inside of the College of Engineering to collect data. After the tests have been run, the data will then be analyzed and processed to create simple graphs and figures that can be easily understood by anyone at a glance. These figures will also include the best location to place the cleaning and measuring equipment around the room the cart is in. Lastly, the final design will be checked to see if it has met the described targets and metrics.

References

APC. (n.d.). *APC Back-UPS, 6 Outlets, 425VA, 120V*. Retrieved from https://www.apc.com/shop/us/en/products/APC-Back-UPS-6-Outlets-425VA-120V/P-BE425M

Blueair. (n.d.). *Pro M*. Retrieved from blueair: https://www.blueair.com/us/pro/pro-m/1408.html?cgid=pro

Environamental Protection Agency . (1990, July). *Ventilation and Air Quality in Offices.* Retrieved from https://www.epa.gov/sites/production/files/2014-08/documents/ventilation_factsheet.pdf

Environmental Protection Agency. (1989). *Report to Congress on Indoor Air Quality*.

Falke, R. (2016, March 24). *Use the Air Changes Calculation to Determine Room CFM*. Retrieved from Contracting Business : https://www.contractingbusiness.com/service/article/20868246/use-the-air-changes-calculation-to-determine-room-cfm

Global Industrial . (n.d.). *Global Industrial™ Mobile Security LCD Computer Workstation, Black, Unassembled*. Retrieved from Global Industrial : https://www.globalindustrial.com/p/office/computer-furniture/cabinets/mobile-security-lcd-computer-cabinet-black-2

Honeywell . (n.d.). *Honeywell Filter A Universal Carbon Pre-Filter, HRF-AP1 (Replaces 38002)*. Retrieved from Honeywell Store: https://www.honeywellstore.com/store/products/honeywell-universal-carbon-pre-filter-hrf-ap1.htm

Honeywell. (2012, November). *E3 Point Specifications.* Retrieved from https://www.instrumart.com/assets/Honeywell-e3point-standalone2-datasheet.pdf

Honeywell. (2019, May). *HPM Series Particulate Matter Sensors.* Retrieved from https://sensing.honeywell.com/honeywell-sensing-particulate-hpm-series-datasheet-32322550.pdf

Honeywell. (n.d.). *Air Quality Monitor.* Retrieved from Honeywell: https://www.honeywellbuildings.in/assets/datasheet/Air_Quality_Monitor_Quick_Start_007618-1-EN.pdf

Honeywell. (n.d.). *DT8035*. Retrieved from Honeywell Home: https://www.security.honeywellhome.com/product-repository/dt8035

Honeywell. (n.d.). *Honeywell True HEPA Bluetooth Smart Air Purifier With Allergen Remover*. Retrieved from Honeywell Store: https://www.honeywellstore.com/store/products/honeywell-hepa-bluetooth-smart-air-purifier-hpa8350b.htm

Honeywell. (n.d.). *Honeywell True HEPA Whole Room Air Purifier With Allergen Remover, HPA300*. Retrieved from Honeywell Store: https://www.honeywellstore.com/store/products/hpa300-true-hepa-whole-room-air-purifier-with-allergen-remover.htm?gclid=Cj0KCQjwit_8BRCoARIsAIx3Rj4begs_A3wW7Kjc6ktbr_sgMQfBrl0BI7Z_4R-9y6KaVkuL60M_dTUaAmQUEALw_wcB

Honeywell. (n.d.). *WPM-8000 - UNIVERSAL POWER SUPPLY FOR JACE-8000 OR LGW1000*. Retrieved from controlconsultantsinc: https://controlconsultantsinc.com/wpm-8000-universal-power-supply-for-jace-8000-or-lgw1000.html

Kele. (n.d.). *PSC100AB10*. Retrieved from Kele: https://www.kele.com/product/power-supplies/transformers/functional-devices/psc100ab10

M. Jeremiah Matson, C. K.-S. (2020). Effect of Environmental Conditions on SARS-CoV-2 Stability in Human Nasal Mucus and Sputum. *Emerging Infectious Diseases*.

Moreno, T., & de Miguel, E. (2018). Improving air quality in subway systems: An overview. *Environmental Pollution* , 829-831.

P3 International . (n.d.). *Kill A Watt EZ*. Retrieved from P3 International : http://www.p3international.com/products/p4460.html

PCE . (n.d.). *Air Quality Meter PCE-RCM 16*. Retrieved from PCE Instruments: https://www.pce-instruments.com/us/measuring-instruments/test-meters/air-quality-meter-pce-instruments-air-quality-meter-pce-rcm-16-det_5927311.htm

Sylvane. (n.d.). *Frequently Asked Questions About Air Purifiers*. Retrieved from Sylvane: https://www.sylvane.com/air-purifier-faq.html#:~:text=High%20Efficiency%20Particulate%20Air%20(HEPA,and%20pollen%20from%20your%20air

Texas Instruments . (2016, May). *PM2.5/PM10 Particle Sensor Analog Front-End for Air*. Retrieved from https://www.ti.com/lit/ug/tidub65c/tidub65c.pdf

Texas Instruments. (2020, 10 30). *PM2.5/PM10 Particle Sensor Analog Front-End for Air*. Retrieved from https://www.ti.com/lit/ug/tidub65c/tidub65c.pdf

Tridium. (n.d.). *JACE 8000*. Retrieved from Tridium : https://www.tridium.com/us/en/Products/niagara/jace-8000

Uline. (n.d.). *Uline 3-Shelf Utility Cart with Flat Shelves - 27 x 18 x 34", Black*. Retrieved from Uline: https://www.uline.com/Product/Detail/H-5007BL/Utility-Carts/Uline-3-Shelf-Utility-Cart-with-Flat-Shelves-27-x-18-x-34-Black?pricode=WA9800&gadtype=pla&id=H-5007BL&gclid=Cj0KCQjwxNT8BRD9ARIsAJ8S5xZs2sqeNe-FNcf0eXoP6YRdOigzw7Grd-wCJlI4rb0sTgOXVDB29_waApxfEA

World Health Organization . (n.d.). *Common Noise*. Retrieved from https://www.who.int/docstore/peh/noise/Comnoise-4.pdf

Appendices

Appendix A: Code of Conduct

Mission Statement

"To improve air quality during our most desperate times."

Roles

Emma Martin: Project Engineer

This position will be responsible for ensuring that the team and project as a whole stay on course. Chief tasks include delegating tasks, including other duties that may arise, staying on top of deadlines, and submitting assignments. Other responsibilities involve organizing meetings with the team sponsor and advisor, taking attendance, maintaining communication within the team encouraging a productive working environment for all team members.

Whitley Pettis: Manufacturing Engineer

Responsible for both the manufacturing and financial aspects of the project. Tasks will include managing budget of project materials and resources in a transparent manner and keeping track of all records, payment history and spending on the project. All budget requests to the sponsor and stakeholders will also be dealt with by the financial advisor. Tasks also include leading the manufacturing process of prototypes of designs created by the design engineer.

Leon Johnson: Test Engineer

This position will be responsible for designing and providing test conditions for product testing, researching scholarly articles to assist with designing, applying methods for testing product functionality, creating design concept ideas, and CAD design work. The CAD work will be in Pro/E and Revit to show the computer-generated model.

Razhan Matipano: Research Engineer

Responsible for researching articles and companies. Tasks will include researching references to help in the ideation process, building a physical model, calculations, and ensuring that the final design matches the design brief. The physical model and the final design will be built off the test engineer's CAD Design work.

Eric Grogans: Electrical Engineer

Responsible for designing and implementing systems involving programming, circuit design, and digital signal processing. Tasks include assessing the feasibility of sensing devices for this application and writing code to communicate between the sensors and control devices. Additionally, is also responsible for the senior design project webpage.

Communication

We will share files through email, Microsoft Teams, and Google Drive when necessary. Day to day communication between group members will be through group text messaging . Communication between the team and advisors or sponsors will be done through email and zoom.

Meetings will be held with our sponsor once a week and advisors at least once a month and should be scheduled at least a week in advance through email; meeting times need to be agreed upon by all parties. If time conflicts arise, meetings will be scheduled when the majority of team members are available.

Team members are expected to check all communication platforms daily and respond to messages from other group members within 24 hours. Replying to messages from the team sponsor or advisor should take no more than three days. All members will be respectful when communicating with each other, sponsors, and advisors at all times.

Attendance Policy and Meeting Expectations

Meetings will occur on Tuesdays and Thursdays after regular Senior Design class sessions, on Mondays and Wednesdays at 5:30 pm, and Fridays at 3:00 pm, except for holidays. We will use an excel file documenting meeting times and dates to keep track of attendance. Unless circumstances occur that prevent attendance to meetings, members should block out the times stated above to meet. If a team member cannot attend a meeting, then they are required to let the group know no later than one day before the meeting. If a team member is absent from three meetings without previously notifying the team of their intended absence, external support will be sought.

The project engineer will conduct meetings. Meetings will be used to delegate task(s), resolve conflicts, meet with advisors, and amend codes. When decisions are being made, a majority vote is needed to pass a proposed idea, including amending the code of conduct. Respect, inclusiveness, and consideration between all members is expected during meetings. Behavior that harms the team dynamic will not be tolerated, this includes explicit language or jokes that are distasteful to anyone in the group, puts them down, or makes them uncomfortable. If other duties not outlined above arise, they will first be offered for team members to volunteer for the role. If no one volunteers, the project engineer will delegate the task to a team member of their choosing.

Dress Code

The dress code for meetings will be as followed: business professional for presentations, business casual for advisor/sponsor meetings, and casual for regular meetings.

Statement of Understanding

By signing this statement, team members understand that they are expected to produce the best work they can, be respectful of their team members and their abilities, and adhere to the above code of conduct.

Name:	Signature:	Date:
Leon Johnson		09/09/2020
Whitley Pettis		09/09/2020
Razhan Matipano		09/09/2020
Emma Martin		09/09/2020
Eric Grogans		09/09/2020

Appendix B: Functional Decomposition

This appendix contains the figures used in the functional decomposition.

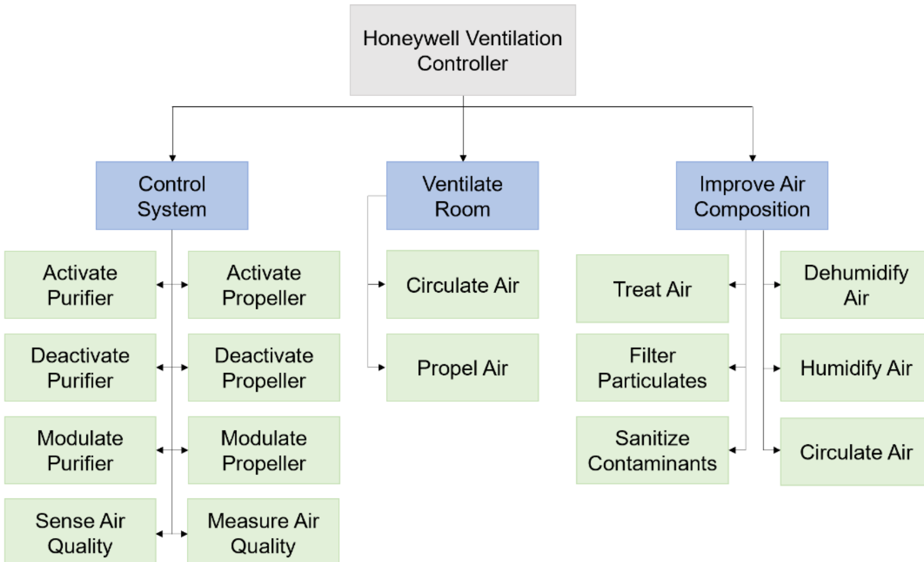

Figure B1. Updated functional decomposition flowchart.

Table B1. *Updated functional decomposition cross-reference table.*

	Major functions		
Minor functions	Control System	Ventilate Room	Improve Air Composition
Sense Air Quality	x		
Activate Propeller	x		
Deactivate Propeller	x		
Modulate Propeller	x		
Activate Purifier	x		
Deactivate Purifier	x		
Modulate Purifier	x		
Measure Air Quality	x		
Propel Air		x	
Circulate Air		x	x
Humidify Air			x
Treat Air			x
Filter Particulates			x
Dehumidify Air			x
Sanitize Contaminants			x
Total	7	2	6

Appendix C: Target Catalog

Table C1. *Full Catalogue of Targets and Metrics.*

Function	Metric	Target
Sense Air Quality	Concentration range of sensors	Particulate sensors detect between 0.1 µg/m^3 and 1000 µg/m^3 [a] Gas sensors detect between 0 ppm and 250 ppm[b]
Measure Air Quality	Accuracy of sensors	Particulate sensors: ±15%[a] Gas sensors: ±3%[b]
Activate Propeller	Reaction time of propeller	6 seconds[a]
Deactivate Propeller	Reaction time of propeller	6 seconds[a]
Modulate Propeller	Reaction time of propeller	6 seconds[a]
Activate Purifier	Reaction time of purifier	6 seconds[a]
Deactivate Purifier	Reaction time of purifier	6 seconds[a]
Modulate Purifier	Reaction time of purifier	6 seconds[a]
Propel Air	Volumetric flowrate of air leaving device per person in room	40 ft^3/min[c]
Circulate Air	Number of air changes per hour	7[d]
Treat Air	Number of changeable filters needed to clean air	3 filters[e]
Filter Particulates	Minimum diameter of particles the device will filter	0.1 µm[f]
Humidify Air	Allowable range of air humidity	40% to 60% humidity[g]
Dehumidify Air	Allowable range of air humidity	40% to 60% humidity[g]
Sanitize Contaminants	Percent of particulates removed from air by device	99%[h]
Device Portability	Volume of device	Less than 10 ft^3 [i]
Device Noise	Noise level	Less than 50 dBA[j]
Energy Consumption	Daily energy consumption of device	80 Watts[k]

Note. Data are from (Honeywell, 2019)[a], (Honeywell, 2012)[b], (Environmental Protection Agency , 1990)[c], (Falke, 2016)[d], (Honeywell, n.d.)[e], (Honeywell , n.d.)[f], (M. Jeremiah Matson, 2020)[g], (Sylvane, n.d.)[h], (Uline, n.d.)[i], (World Health Organization , n.d.)[j], (Blueair, n.d.)[k].

Appendix D: 100 Design Concepts

This Appendix contains a catalogue of 100 design concepts created during the concept generation phase of the project. The concepts are split into sections depending on which concept generation tool or method was used. The methods are shown in the headings of each section. Medium and high-fidelity concepts can be seen in section 1.6 of this report.

Brainstorming

1. Fill the room with plants, use sensors to monitor air quality
2. Fill room with water, now there is no air quality to deal with
3. Make everyone wear very high-quality masks all the time so they have good air quality no matter what the quality of the room is
4. Every night, completely suck all the air from the college of engineering and replace it with new clean air
5. Ban people from the college of engineering so the air quality is no longer an issue
6. Add more windows to the college for greater airflow
7. Place a canary in the college, if the canary gets sick or dies, the air quality of the room is unsafe
8. Constantly purify the air in the room to ensure it can't reach unhealthy levels
9. Constantly vent air out of rooms where that pass a certain occupancy threshold
10. Evacuate rooms with poor air quality and wait until it reaches normal levels
11. Bring air in from unoccupied rooms when air quality becomes poor
12. Count number of people entering a room and enable cleaning system when it reaches a threshold
13. A single cart containing sensors to measure air quality, and air purifiers, dehumidifiers, and fans to improve the air quality. All devices will be battery powered
14. Once cart containing sensors to measure air quality and a second cart containing cleaning devices, such as air purifiers, fans, and dehumidifiers
15. Raise temperature in the room to sanitize the air
16. To monitor air quality, survey people and see if they think the air quality is bad
17. BYOO (bring your own oxygen). The room is a complete vacuum, so it is literally impossible to have bad air.
18. Design & create a simple HVAC system and add onto the existing system
19. Add small fans blowing towards a cart containing cleaning equipment for increased air circulation & sensibility
20. A moving cart containing cleaning with a designed pathway. Adding small motors & sensors for stopping & pathway
21. A cart with a pressure system added to increase circulation

22. Open door and place a cart containing cleaning equipment beside the entrance point. This would add a pathway for circulation in a positive or negative air-filled room
23. Adding a small black light or lights near device to get a better visual of particulate motion during circulation
24. Add Clorox wipes to filter/filters to better "clean" air during filtration.
25. Add rectangular vents for exit points in air circulation on device. A rectangular jet causes a shear layer also known as a "mixing layer" with air flow
26. Spray cleaning spray into the air, this will help "clean" air and the spray can be manual or automatic
27. Add sensors to 4 corners of the room and place a cleaning cart in the center of the room to get a room size analysis on air quality
28. Place a cleaning cart next to room air duct to better assist room with air purification
29. Add phone charging ports to cart for improved personal interaction with device.
30. Add silent alarm whenever there is a dangerous number of particulates or chemicals in the air
31. Our project can be compared to a velocity flow field inside a room. Our device is trying to create a pressure difference to pull particulates in and circulate clean air out
32. Device can take a finite element method approach. The cart will be placed in multiple positions while measuring variables. A 3D model can be made based on the data collected in different spots for the cart.
33. Add fake plants and signs saying "Good Air Quality" to trick people into thinking the air is cleaner
34. L-shaped air purifier on a cart. Incoming air passes through 3 filters, air is directed upwards at exit
35. Variation of idea 32 with one of the filters toward the end of the outlet. The last filter will catch excess particles from the bend of the L
36. A stationary air purifier that looks like a tree; takes air in from below to be filtered out through branch-like outputs; large.
37. Variation of idea 34 with a small output of air which would be useful for smaller areas
38. Air purifier with a mesh grid at the top, contains filters and a UV light to purify air
39. Air purifier with 2 filters, for areas clean of large matter; Has cooling coils
40. Purifier with exhaust air that is aimed towards existing vents in room
41. Purifier with 2 fans, inner fan redirects the flow of air in system; lightweight as possible for small rooms
42. A wireless network air purifier; Can be mobile and accessed through an app
43. Triangular prism shaped air purifier with mobile network function
44. Air purifier is decorated with fake plants to trick people into thinking the air is being naturally cleaned
45. Variation of idea 44, with sensors on top, under the fake garden to hide controls.
46. Air purifier with rotary functions to capture and release air all around
47. Air purifier with lights to indicate air quality, sensors connect wirelessly to lights

48. Air purifier, dehumidifier, and sensors that are mounted to walls and, vents, and existing HVAC infrastructure.

Biomimicry

The natural organisms used for each idea is shown at the beginning of the concept

49. Deer Alert System – The system gathers information similar to how a deer uses its keen senses. The device with alert the area when something is wrong just like a deer does.
50. Elephant Cleaning System – When the room is determined to be not clean and unhealthy the device will spray the room with sanitizer like an elephant sprays water to clean itself.
51. Honeybee Cleaning – The device will contain thousands of tiny robots and will release them to clean the air.
52. Hawk/Eagle Monitor and Alert – The device will monitor the air with devices that can see and hear very well and will make a screeching noise when it notices that something is wrong with the air in the room.
53. Scavenger System – the system will scavenge the room to clean up after people have left it dirty and unclean
54. Oyster Sanitation System – When the door is opened to the room and the device has detected a guest the device will begin a sanitation cycle that sprays the entire room, much like oysters do to clean the water around them.
55. Cat Cleaning System – This system will be set on a timer and the device will clean the room in increments throughout the day similar to how cats clean themselves periodically throughout the day.
56. Polar Bear System – In order to combat the growth of bacteria and viruses the system will start a cooling cycle when the temperature is too high like how a polar bear is able to regulate their body temperature.
57. Bottom Feeder Cleaning – Similar to how some fish feed on the bottom of an aquarium to clean it the device will constantly sweep the room to ensure that it is clean.
58. Bird Nest Cleaning – The device will fly around the room destroying viruses and picking up anything that is unsanitary much like a bird carries away the baby bird's poop and cleans the nest.
59. Hippo Bath – At night the room will be sealed off and completely flooded to clean the room
60. Rain Shower – Similar to how rain cleanses the air in nature the buildings sprinklers will be turned on and cleanse the dirty room.
61. Tornado System – Much like how a tornado destroys things, the system will contain a giant fan to blow through the room to push out the bad air and destroy the bad pathogens.
62. Human Breathing – The device with act similar to the way a human breathes by intaking air that is currently in the room. It will sense and filter the air then release the bad air outside through a vent and will keep the good air circulating through the room.

Forced Analogy

The analogy used for each idea is shown at the beginning of the concept

63. Projector - Use a UV light to kill pathogens and clean air
64. Projector - Use a projector light in a dark room to see areas where there is the most visible contamination in a room
65. Ceiling fan - Use large fans to blow air towards vents/UV lights for sanitation
66. Thermostat - Cleaning devise should have sensors to count the amount of people in a room, when a critical amount of people has been identified, the devise will switch off
67. Thermostat - The devise should automatically switch on, but have an emergency stop button so it can be turned off in the case of a malfunction
68. Classroom - Our project relates to a closed-circuit system with air flow continuously circulating through room
69. Wind Tunnel - Air circulating device can be compared to a wind tunnel due to changes in pressure and air circulation
70. Analogue to Digital Sensor - Our device can be compared to a data acquisition software that takes real world physics and converts variables into a digital value

Crap Shoot

71. Go-Kart engines are used to power the device
72. A priest blesses the air at the college, making it holy
73. Students are given rocking chairs to sit on, the kinetic energy they produce from rocking is used to power the device
74. The devise will be powered by solar panels
75. Have a vacuum running all the times to suck particulates and debris out of the air

Anti-problem

76. Use filters to remove solid particulates from the air
77. Require people to be tested for COVID-19 and other common airborne diseases before they can enter college
78. Require people to walk through spray-down sanitation tents and wear hypoallergenic suits before they can enter the college to reduce the introduction of pathogens and other contaminants in the college

Morphological Chart

The following ideas came from the morphological chart shown below

Ventilation	Control System	Sanitize	Humidity Control
Fan	Phone App	Sprayer	Dehumidifier
Vent	Computer Program	Filters	Water Fan
	Buttons	Diffuser	Heat Lamp
		UV Light	

79. Ventilate using a fan, control the system using a phone app, sanitize using a sprayer, and control the humidity using a dehumidifier.
80. Ventilate using a fan, control the system using a computer, sanitize using sprayer, and control humidity using a dehumidifier.
81. Ventilate using a fan, control the system using buttons, sanitize using a sprayer, and control the humidity using a dehumidifier.
82. Ventilate using a vent, control the system using a phone app, sanitize using a sprayer, and control the humidity using a dehumidifier.
83. Ventilate using a vent, control the system using a computer, sanitize using sprayer, and control humidity using a dehumidifier.
84. Ventilate using a vent, control the system using buttons, sanitize using a sprayer, and control the humidity using a dehumidifier.
85. Ventilate using a fan, control the system using a phone app, sanitize using filters, and control the humidity using a dehumidifier.
86. Ventilate using a fan, control the system using a phone app, sanitize using diffusers, and control the humidity using a dehumidifier.
87. Ventilate using a fan, control the system using a phone app, sanitize using a UV light, and control the humidity using a dehumidifier.
88. Ventilate using a vent, control the system using a phone app, sanitize using filters, and control the humidity using a dehumidifier.
89. Ventilate using a vent, control the system using a phone app, sanitize using diffusers, and control the humidity using a dehumidifier.
90. Ventilate using a vent, control the system using a phone app, sanitize using UV light, and control the humidity using a dehumidifier.
91. Ventilate using a fan, control the system using a computer, sanitize using filters, and control the humidity using a dehumidifier.
92. Ventilate using a fan, control the system using a computer, sanitize using diffusers, and control the humidity using a dehumidifier.
93. Ventilate using a fan, control the system using a computer, sanitize using a UV light, and control the humidity using a dehumidifier.

94. Ventilate using a fan, control the system using buttons, sanitize using filters, and control the humidity using a dehumidifier.
95. Ventilate using a fan, control the system using buttons, sanitize using diffusers, and control the humidity using a dehumidifier.
96. Ventilate using a fan, control the system using buttons, sanitize using a UV light, and control the humidity using a dehumidifier.
97. Ventilate using a vent, control the system using a phone app, sanitize using diffusers, and control the humidity using a water fan.
98. Ventilate using a vent, control the system using a phone app, sanitize using a UV light, and control the humidity using a heat lamp.
99. Ventilate using a fan, control the system using a phone app, sanitize using diffusers, and control the humidity using a water fan.
100. Ventilate using a fan, control the system using a phone app, sanitize using a UV light, and control the humidity using a heat lamp.

Appendix E: AHP Tables

Table E1. *Development of Candidate Set of Criteria Weights {W}.*

Development of Candidate Set of Criteria Weights {W}												
Criteria Comparison Matrix [C]												
Engineering Characteristics	Portability	Sense air Quality	Propeller Activation	Propeller Modulation	Purifier Activation	Purifier Modulation	Air Propulsion	Air Purification	Air Treatment	Filter Particulates	Humidify	Sanitize
Portability	1.00	3.00	0.14	0.14	0.14	0.14	0.20	0.20	0.20	0.20	0.20	3.00
Sense air Quality	0.33	1.00	0.14	0.20	0.20	0.20	0.20	0.14	0.14	0.14	0.33	5.00
Propeller Activation	7.00	5.00	1.00	7.00	1.00	3.00	0.33	0.14	0.14	0.14	0.20	0.14
Propeller Modulation	7.00	5.00	0.14	1.00	0.14	1.00	0.33	0.14	0.14	0.14	0.20	0.14
Purifier Activation	7.00	5.00	1.00	7.00	1.00	5.00	0.33	0.14	0.20	0.20	0.20	0.14
Purifier Modulation	7.00	5.00	0.33	1.00	0.20	1.00	0.33	0.20	0.20	0.20	0.20	0.20
Air Propulsion	5.00	5.00	3.00	3.00	3.00	3.00	1.00	0.33	0.33	0.20	0.20	0.33
Air Purification	5.00	7.00	7.00	7.00	7.00	5.00	3.00	1.00	1.00	0.33	0.20	0.33
Air Treatment	5.00	7.00	7.00	7.00	5.00	5.00	3.00	1.00	1.00	0.33	3.00	3.00
Filter Particulates	5.00	7.00	7.00	7.00	5.00	5.00	5.00	3.00	3.00	1.00	5.00	5.00
Humidify	5.00	3.00	5.00	5.00	5.00	5.00	5.00	5.00	0.33	0.20	1.00	1.00
Sanitize	0.33	0.20	7.00	7.00	7.00	5.00	3.00	3.00	0.33	0.20	1.00	1.00
Sum	54.67	53.20	38.76	52.34	34.69	38.34	21.73	14.30	7.03	3.30	11.73	19.30

Table E2. *Further Development of Candidate Set of Criteria Weights {W}.*

Development of Candidate Set of Criteria Weights {W}													
Normalized Criteria Comparison Matrix [NormC]													
Engineering Characteristics	Portability	Sense air Quality	Propeller Activation	Propeller Modulation	Purifier Activation	Purifier Modulation	Air Propulsion	Air Purification	Air Treatment	Filter Particulates	Humidify	Sanitize	Criteria Weight {W}
Portability	0.0183	0.0564	0.0037	0.0027	0.0041	0.0037	0.0092	0.0140	0.0284	0.0606	0.0171	0.1554	0.0311
Sense air Quality	0.0061	0.0188	0.0037	0.0038	0.0058	0.0052	0.0092	0.0100	0.0203	0.0433	0.0284	0.2591	0.0345
Propeller Activation	0.1280	0.0940	0.0258	0.1337	0.0288	0.0782	0.0153	0.0100	0.0203	0.0433	0.0171	0.0074	0.0502
Propeller Modulation	0.1280	0.0940	0.0037	0.0191	0.0041	0.0261	0.0153	0.0100	0.0203	0.0433	0.0171	0.0074	0.0324
Purifier Activation	0.1280	0.0940	0.0258	0.1337	0.0288	0.1304	0.0153	0.0100	0.0284	0.0606	0.0171	0.0074	0.0566
Purifier Modulation	0.1280	0.0940	0.0086	0.0191	0.0058	0.0261	0.0153	0.0140	0.0284	0.0606	0.0171	0.0104	0.0356
Air Propulsion	0.0915	0.0940	0.0774	0.0573	0.0865	0.0782	0.0460	0.0233	0.0474	0.0606	0.0171	0.0173	0.0580
Air Purification	0.0915	0.1316	0.1806	0.1337	0.2018	0.1304	0.1381	0.0699	0.1422	0.1010	0.0171	0.0173	0.1129
Air Treatment	0.0915	0.1316	0.1806	0.1337	0.1441	0.1304	0.1381	0.0699	0.1422	0.1010	0.2558	0.1554	0.1395
Filter Particulates	0.0915	0.1316	0.1806	0.1337	0.1441	0.1304	0.2301	0.2098	0.4267	0.3030	0.4263	0.2591	0.2222
Humidify	0.0915	0.0564	0.1290	0.0955	0.1441	0.1304	0.2301	0.3497	0.0474	0.0606	0.0853	0.0518	0.1226
Sanitize	0.0061	0.0038	0.1806	0.1337	0.2018	0.1304	0.1381	0.2098	0.0474	0.0606	0.0853	0.0518	0.1041
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table E3. *Development of Weighted Sum Vectors {Ws}.*

Development of Weighted Sum Vectors {Ws}													
Engineering Characteristics	**Portability**	**Sense air Quality**	**Propeller Activation**	**Propeller Modulation**	**Purifier Activation**	**Purifier Modulation**	**Air Propulsion**	**Air Purification**	**Air Treatment**	**Filter Particulates**	**Air Humidification**	**Sanitize Contaminants**	**Weighted Sum {Ws}**
Portability	0.0311	0.1034	0.0072	0.0046	0.0081	0.0051	0.0116	0.0226	0.0279	0.0444	0.0245	0.0312	0.3218
Sense air Quality	0.0104	0.0345	0.0072	0.0065	0.0113	0.0071	0.0116	0.0161	0.0199	0.0317	0.0409	0.0521	0.2493
Propeller Activation	0.2177	0.1724	0.0502	0.2266	0.0566	0.1068	0.0194	0.0161	0.0199	0.0317	0.0245	0.0015	0.9435
Propeller Modulation	0.2177	0.1724	0.0072	0.0324	0.0081	0.0356	0.0194	0.0161	0.0199	0.0317	0.0245	0.0015	0.5865
Purifier Activation	0.2177	0.1724	0.0502	0.2266	0.0566	0.1781	0.0194	0.0161	0.0279	0.0444	0.0245	0.0015	1.0354
Purifier Modulation	0.2177	0.1724	0.0167	0.0324	0.0113	0.0356	0.0194	0.0226	0.0279	0.0444	0.0245	0.0021	0.6270
Air Propulsion	0.1555	0.1724	0.1506	0.0971	0.1699	0.1068	0.0581	0.0376	0.0465	0.0444	0.0245	0.0035	1.0670
Air Purification	0.1555	0.2413	0.3514	0.2266	0.3965	0.1781	0.1742	0.1129	0.1395	0.0741	0.0245	0.0035	2.0780
Air Treatment	0.1555	0.2413	0.3514	0.2266	0.2832	0.1781	0.1742	0.1129	0.1395	0.0741	0.3680	0.0312	2.3359
Filter Particulates	0.1555	0.2413	0.3514	0.2266	0.2832	0.1781	0.2903	0.3388	0.4186	0.2222	0.6133	0.0521	3.3712
Air Humidification	0.1555	0.1034	0.2510	0.1619	0.2832	0.1781	0.2903	0.5647	0.0465	0.0444	0.1227	0.0104	2.2119
Sanitize Contaminants	0.0104	0.0069	0.3514	0.2266	0.3965	0.1781	0.1742	0.3388	0.0465	0.0444	0.1227	0.0104	1.9067
Sum	1.70	1.83	1.95	1.69	1.96	1.37	1.26	1.62	0.98	0.73	1.44	0.20	16.73

Appendix F: Engineering Drawings

This appendix contains the models of B-135 and the senior design lab, the rooms in the FAMU-FSU College of Engineering used for simulations.

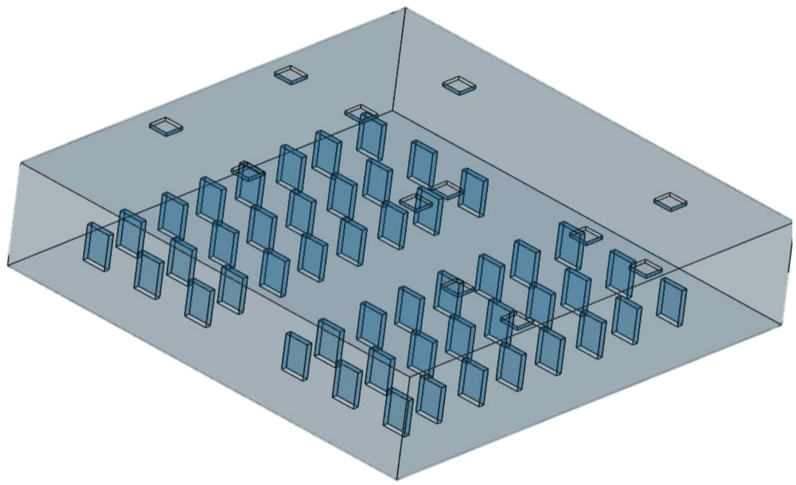

Figure F1. Model of B-135. Squares on ceiling represent vents, rectangular blocks on the floor represent people.

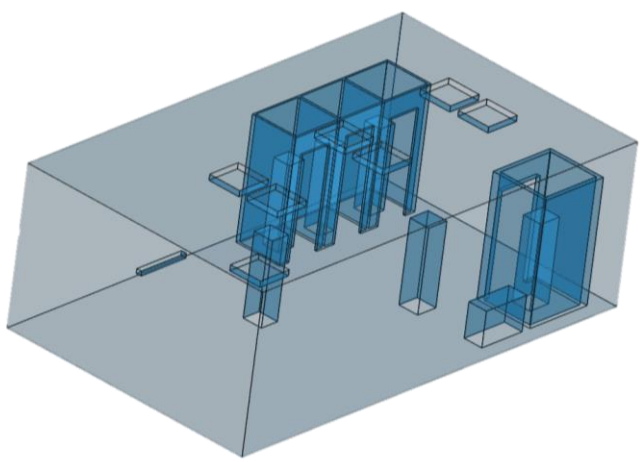

Figure F2. Model of the senior design lab containing vents, people, cubicles, and a sink.

Appendix G: Calculations

All calculations were completed to by a computational fluid dynamics (CFD) software to create airflow simulations of our chosen testing locations. This appendix contains the resulting CFD simulations.

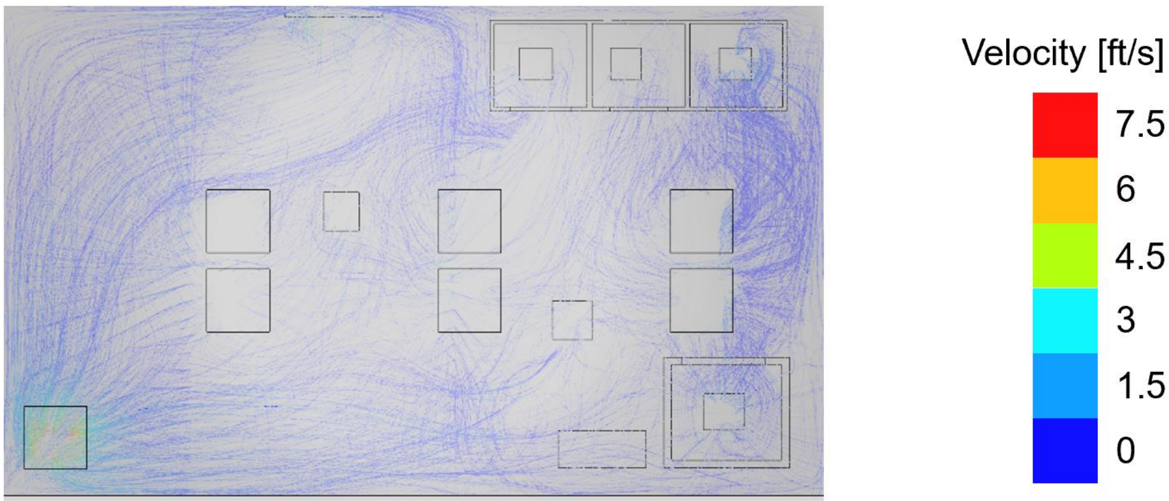

Figure G1. Airflow simulation or the Mechanical Engineering Senior Design Lab – top view.

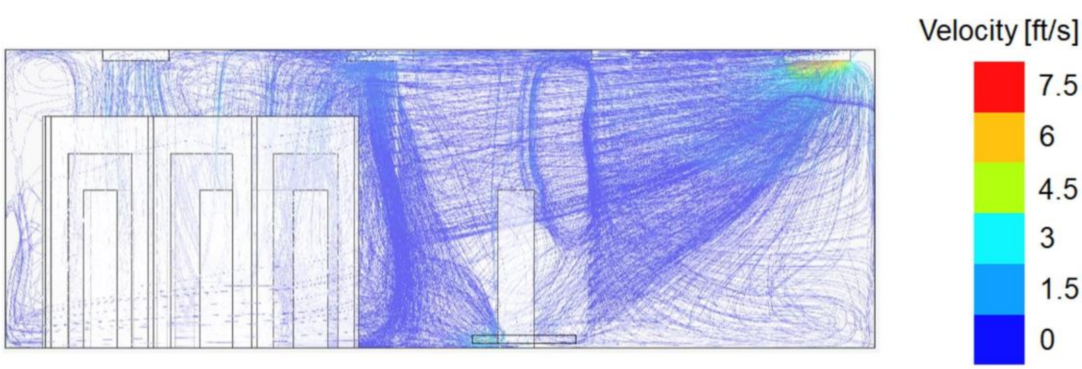

Figure G2. Airflow simulation or the Mechanical Engineering Senior Design Lab – side view.

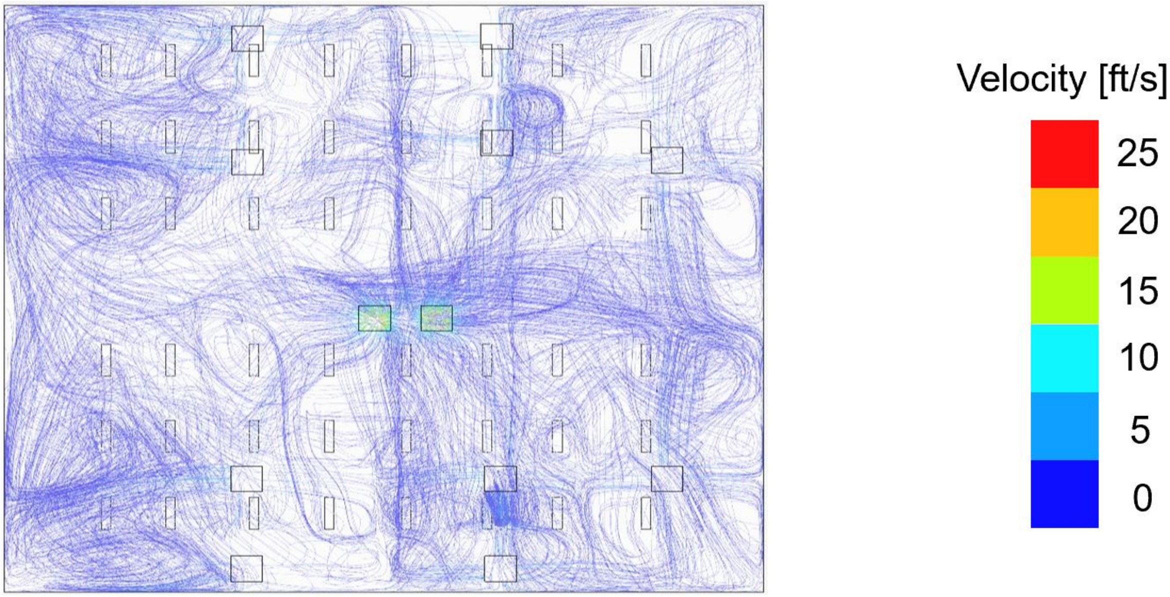

Figure G3. Airflow simulation or the classroom B135 – top view.

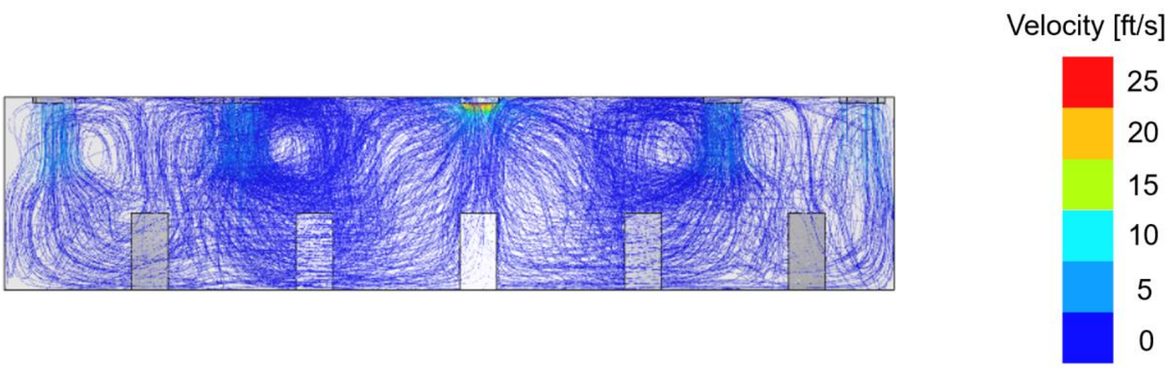

Figure G3. Airflow simulation or the classroom B135 – top view.

Appendix H: Risk Assessment

Project Hazard Control- For Projects with Medium and Higher Risks

Name of Project:		**Date of submission:**
Team member	**Phone number**	**e-mail**
Eric Grogans	(561)-479-8520	eg17b@my.fsu.edu
Leon Johnson	(786)-277-1316	ltj17@my.fsu.edu
Emma Martin	(850)-567-6546	ecm17@my.fsu.edu
Razhan Matipano	(863)-651-7552	razhan1.matipano@famu.edu
Whitley Pettis	(850)-303-1667	wbp18@my.fsu.edu
Faculty mentor	**Phone number**	**e-mail**
Dr. McConomy	(850)-410-6624	smcconomy@eng.famu.fsu.edu
Dr. Yaghoobian	(850) 645-0142	nyaghoobian@eng.famu.fsu.edu

Rewrite the project steps to include all safety measures taken for each step or combination of steps. Be specific (don't just state "be careful").

Locating Cart: Hazards include, blocking emergency exits (OSHA 1910 Subpart E) and creating tripping hazards with extension cords. Safety measures include complying with OSHA standards and carefully placing cords out of walkways.

Running Equipment: Hazards include, damaged electrical cords causing fires, overloading an outlet can cause a fire. Safety measures include inspecting and testing cords and equipment before use (OSHA 1910.334) and plugging equipment into a surge protector.

Thinking about the accidents that have occurred or that you have identified as a risk, describe emergency response procedures to use.

In the event of a minor injury we will call our faculty mentors and inform them of the injury. If an injury is more serious we will call emergency services for medical advice. In the event of an electrical fire we will imediatley call 911 to notify the fire department. We will also inform our faculty advisors and building facilities of the incident.
List emergency response contact information:
• Call 911 for injuries, fires or other emergency situations • Call your department representative to report a facility concern

Name	Phone number	Faculty or other COE emergency contact	Phone number
Sawyer O'Bryan	(850)-557-3995	Dr. McConomy	(850)-410-6624
Christina Portuallo	(386)-503-9019	Donald Hollett	(850)-410-6600

Safety review signatures

Team member	Date	Faculty mentor	Date
Eric Grogans	12/3/20		
Leon Johnson	12/3/20		
Emma Martin	12/3/20		
Razhan Matipano	12/3/20		
Whitley Pettis	12/3/20		

Report all accidents and near misses to the faculty mentor.

FAMU-FSU College of Engineering
Project Hazard Assessment Policy and Procedures

INTRODUCTION

University laboratories are not without safety hazards. Those circumstances or conditions that might go wrong must be predicted and reasonable control methods must be determined to prevent incident and injury. The FAMU-FSU College of Engineering is committed to achieving and maintaining safety in all levels of work activities.

PROJECT HAZARD ASSESSMENT POLICY

Principal investigator (PI)/instructor are responsible and accountable for safety in the research and teaching laboratory. Prior to starting an experiment, laboratory workers must conduct a project hazard assessment (PHA) to identify health, environmental and property hazards and the proper control methods to eliminate, reduce or control those hazards. PI/instructor must review, approve, and sign the written PHA and provide the identified hazard control measures. PI/instructor continually monitor projects to ensure proper controls and safety measures are available, implemented, and followed. PI/instructor are required to reevaluate a project anytime there is a change in scope or scale of a project and at least annually after the initial review.

PROJECT HAZARD ASSESSMENT PROCEDURES

It is FAMU-FSU College of Engineering policy to implement followings:

1. Laboratory workers (i.e. graduate students, undergraduate students, postdoctoral, volunteers, etc.) performing a research in FAMU-FSU College of Engineering are required to conduct PHA prior to commencement of an experiment or any project change in order to identify existing or potential hazards and to determine proper measures to control those hazards.
2. PI/instructor must review, approve and sign the written PHA.
3. PI/instructor must ensure all the control methods identified in PHA are available and implemented in the laboratory.
4. In the event laboratory personnel are not following the safety precautions, PI/instructor must take firm actions (e.g. stop the work, set a meeting to discuss potential hazards and consequences, ask personnel to review the safety rules, etc.) to clarify the safety expectations.
5. PI/instructor must document all the incidents/accidents happened in the laboratory along with the PHA document to ensure that PHA is reviewed/modified to prevent reoccurrence. In the event of PHA modification a revision number should be given to the PHA, so project members know the latest PHA revision they should follow.
6. PI/instructor must ensure that those findings in PHA are communicated with other students working in the same laboratory (affected users).

7. PI/instructor must ensure that approved methods and precautions are being followed by :
    a. Performing periodic laboratory visits to prevent the development of unsafe practice.
    b. Quick reviewing of the safety rules and precautions in the laboratory members meetings.
    c. Assigning a safety representative to assist in implementing the expectations.
    d. Etc.
8. A copy of this PHA must be kept in a binder inside the laboratory or PI/instructor's office (if experiment steps are confidential).

Project Hazard Assessment Worksheet				
PI/instructor: Dr. Shayne McConomy	Phone #: 850-410-6624	Dept.: ME	Start Date: 12/01/2020	Revision number: 1
Project: Honeywell Indoor Air Quality of Hotspots			Location(s): Senior Design Lab, Building A Atrium, Classroom B135	
Team member(s): Eric Grogans, Leon Johnson, Emma Martin, Razhan Matipano, Whitley Pettis			Phone #: (850)-567-6546	Email: ecm17@my.fsu.edu

Experiment Steps	**Location**	**Person assigned**	**Identify hazards or potential failure points**	**Control method**	**PPE**	**List proper method of hazardous waste disposal, if any.**	**Residual Risk**	**Specific rules based on the residual risk**
Assemble Devices	Senior Design Lab	All Team Members	Lifting heavy objects, Cuts from sharp edges	Don't lift heavy objects or assemble without somebody else present	Long pants, closed toed shoes	N/A	HAZARD: 2 CONSEQ: Negligible Residual: Low	Safety controls planned by worker and supervisor. Proceed with supervisor authorization.
Load Carts	Senior Design Lab	All Team Members		Don't lift heavy objects alone.	Long pants,	N/A	HAZARD: 1	

			Lifting heavy objects, pinching fingers, Exceeding cart weight limit	Take car when placing objects, check devices do not exceed cart weight limit	closed toed shoes		CONSEQ: Minor Resi dual: Low	Safety controls planned by worker and supervisor. Proceed with supervisor authorization.
Locating Carts	College of Engineering	All Team Members	Blocking Emergency exits (OSHA 1910 Subpart E), creating tripping hazards with extension cords	Comply with OSHA standards, carefully place cords out of walkways	Closed toed shoes	N/A	HAZARD: 1 CONSEQ: Moderate Resi dual: Low Med	Safety controls planned by worker and supervisor. Buddy system. Proceed with supervisor authorization.
Running Equipment	College of Engineering	All Team Members	Damaged electrical cords can cause fires, overload an outlet	Inspect and test cords before use (OSHA 1910.334), plug equipment into surge protector	Eye protecti on, gloves	N/A	HAZARD: 3 CONSEQ: Minor Residual: Low Med	Safety controls planned by worker and supervisor. Buddy system. Proceed with supervisor authorization.

Principal investigator(s)/ instructor PHA: I have reviewed and approved the PHA worksheet.

Name	**Signature**	**Date**	**Name**	**Signature**	**Date**
______________________	_______________	_________	_______________________	_______________	______

Team members: I certify that I have reviewed the PHA worksheet, am aware of the hazards, and will ensure the control measures are followed.

Name	Signature	Date	Name	Signature	Date
Eric Grogans______________		12/3/20__	Leon Johnson_____________		12/3/20__
Emma Martin_____________	Emma Martin	12/3/20__	Razhan Matipano__________	Razhan Matipano	12/3/20__
WhitleyPettis_____________		12/3/20__			

Copy this page if more space is needed.

DEFINITIONS:

Hazard: Any situation, object, or behavior that exists, or that can potentially cause ill health, injury, loss or property damage e.g. electricity, chemicals, biohazard materials, sharp objects, noise, wet floor, etc. OSHA defines hazards as "*any source of potential damage, harm or adverse health effects on something or someone".* A list of hazard types and examples are provided in appendix A.

Hazard control: Hazard control refers to workplace measures to eliminate/minimize adverse health effects, injury, loss, and property damage. Hazard control practices are often categorized into following three groups (priority as listed):

1. **Engineering control:** physical modifications to a process, equipment, or installation of a barrier into a system to minimize worker exposure to a hazard. Examples are ventilation (fume hood, biological safety cabinet), containment (glove box, sealed containers, barriers), substitution/elimination (consider less hazardous alternative materials), process controls (safety valves, gauges, temperature sensor, regulators, alarms, monitors, electrical grounding and bonding), etc.
2. **Administrative control:** changes in work procedures to reduce exposure and mitigate hazards. Examples are reducing scale of process (micro-scale experiments), reducing time of personal exposure to process, providing training on proper techniques, writing safety policies, supervision, requesting experts to perform the task, etc.
3. **Personal protective equipment (PPE):** equipment worn to minimize exposure to hazards. Examples are gloves, safety glasses, goggles, steel toe shoes, earplugs or muffs, hard hats, respirators, vests, full body suits, laboratory coats, etc.

Team member(s): Everyone who works on the project (i.e. grads, undergrads, postdocs, etc.). The primary contact must be listed first and provide phone number and email for contact.

Safety representative: Each laboratory is encouraged to have a safety representative, preferably a graduate student, in order to facilitate the implementation of the safety expectations in the laboratory. Duties include (but are not limited to):

- Act as a point of contact between the laboratory members and the college safety committee members.
- Ensure laboratory members are following the safety rules.
- Conduct periodic safety inspection of the laboratory.
- Schedule laboratory clean up dates with the laboratory members.
- Request for hazardous waste pick up.

Residual risk: Residual Risk Assessment Matrix are used to determine project's risk level. The hazard assessment matrix (table 1) and the residual risk assessment matrix (table2) are used to identify the residual risk category.

The instructions to use hazard assessment matrix (table 1) are listed below:

1. Define the workers familiarity level to perform the task and the complexity of the task.
2. Find the value associated with familiarity/complexity (1 – 5) and enter value next to: HAZARD on the PHA worksheet.

Table 1. Hazard assessment matrix.

		Complexity		
		Simple	Moderate	Difficult
Familiarity Level	Very Familiar	1	2	3
	Somewhat Familiar	2	3	4
	Unfamiliar	3	4	5

The instructions to use residual risk assessment matrix (table 2) are listed below:

1. Identify the row associated with the familiarity/complexity value (1 – 5).
2. Identify the consequences and enter value next to: CONSEQ on the PHA worksheet. Consequences are determined by defining what would happen in a worst case scenario if controls fail.

a. Negligible: minor injury resulting in basic first aid treatment that can be provided on site.
b. Minor: minor injury resulting in advanced first aid treatment administered by a physician.
c. Moderate: injuries that require treatment above first aid but do not require hospitalization.
d. Significant: severe injuries requiring hospitalization.
e. Severe: death or permanent disability.

3. Find the residual risk value associated with assessed hazard/consequences: Low –Low Med – Med– Med High – High.
4. Enter value next to: RESIDUAL on the PHA worksheet.

Table 2. Residual risk assessment matrix.

Assessed Hazard Level	**Consequences**				
	Negligible	Minor	Moderate	Significant	Severe
5	Low Med	Medium	Med High	High	High
4	Low	Low Med	Medium	Med High	High
3	Low	Low Med	Medium	Med High	Med High
2	Low	Low Med	Low Med	Medium	Medium
1	Low	Low	Low Med	Low Med	Medium

Specific rules for each category of the residual risk:

Low:

- Safety controls are planned by both the worker and supervisor.
- Proceed with supervisor authorization.

Low Med:

- Safety controls are planned by both the worker and supervisor.
- A second worker must be in place before work can proceed (buddy system).
- Proceed with supervisor authorization.

Med:

- After approval by the PI, a copy must be sent to the Safety Committee.
- A written Project Hazard Control is required and must be approved by the PI before proceeding. A copy must be sent to the Safety Committee.
- A second worker must be in place before work can proceed (buddy system).
- Limit the number of authorized workers in the hazard area.

Med High:

- After approval by the PI, the Safety Committee and/or EHS must review and approve the completed PHA.
- A written Project Hazard Control is required and must be approved by the PI and the Safety Committee before proceeding.
- Two qualified workers must be in place before work can proceed.
- Limit the number of authorized workers in the hazard area.

High:

- The activity will not be performed. The activity must be redesigned to fall in a lower hazard category.

Appendix A: Hazard types and examples

Types of Hazard	**Example**
Physical hazards	Wet floors, loose electrical cables objects protruding in walkways or doorways
Ergonomic hazards	Lifting heavy objects Stretching the body Twisting the body Poor desk seating
Psychological hazards	Heights, loud sounds, tunnels, bright lights
Environmental hazards	Room temperature, ventilation contaminated air, photocopiers, some office plants acids
Hazardous substances	Alkalis solvents
Biological hazards	Hepatitis B, new strain influenza
Radiation hazards	Electric welding flashes Sunburn

Chemical hazards	Effects on central nervous system, lungs, digestive system, circulatory system, skin, reproductive system. Short term (acute) effects such as burns, rashes, irritation, feeling unwell, coma and death. Long term (chronic) effects such as mutagenic (affects cell structure), carcinogenic (cancer), teratogenic (reproductive effect), dermatitis of the skin, and occupational asthma and lung damage.
Noise	High levels of industrial noise will cause irritation in the short term, and industrial deafness in the long term.
Temperature	Personal comfort is best between temperatures of 16°C and 30°C, better between 21°C and 26°C. Working outside these temperature ranges: may lead to becoming chilled, even hypothermia (deep body cooling) in the colder temperatures, and may lead to dehydration, cramps, heat exhaustion, and hyperthermia (heat stroke) in the warmer temperatures.
Being struck by	This hazard could be a projectile, moving object or material. The health effect could be lacerations, bruising, breaks, eye injuries, and possibly death.
Crushed by	A typical example of this hazard is tractor rollover. Death is usually the result
Entangled by	Becoming entangled in machinery. Effects could be crushing, lacerations, bruising, breaks amputation and death.
High energy sources	Explosions, high pressure gases, liquids and dusts, fires, electricity and sources such as lasers can all have serious effects on the body, even death.
Vibration	Vibration can affect the human body in the hand arm with `white-finger' or Raynaud's Syndrome, and the whole body with motion sickness, giddiness, damage to bones and audits, blood pressure and nervous system problems.
Slips, trips and falls	A very common workplace hazard from tripping on floors, falling off structures or down stairs, and slipping on spills.
Radiation	Radiation can have serious health effects. Skin cancer, other cancers, sterility, birth deformities, blood changes, skin burns and eye damage are examples.
Physical	Excessive effort, poor posture and repetition can all lead to muscular pain, tendon damage and deterioration to bones and related structures
Psychological	Stress, anxiety, tiredness, poor concentration, headaches, back pain and heart disease can be the health effects
Biological	More common in the health, food and agricultural industries. Effects such as infectious disease, rashes and allergic response.