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EML4551-2

Team 520: Trane: Improve Air Quality

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Abstract

Due to the pressing times of COVID-19, an HVAC solution is needed to ensure air quality meets the necessary requirements. This project is to develop an energy-efficient retrofit HVAC solution that improves air quality while adhering to current government/environmental guidelines to combat COVID-19. It will continue to be sustainable in future markets for residential and commercial applications.

Keywords: HVAC, air quality, coronavirus

Disclaimer

Your sponsor may require a disclaimer on the report. Especially if it is a government sponsored project or confidential project. If a disclaimer is not required delete this section.

Acknowledgement

We would like to thank our sponsor Cameron Griffith with Trane for taking the time to meet with us to provide us with the necessary information about our project. We would also like to thank Dr. McConomy and Dr. Ordonez for giving us mentorship throughout this project. We also wish to thank Jim Stephens for giving us insight into FSU's Utilities and Maintenance operations.

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Notation

Chapter One: EML 4551C

1.1 Project Scope

Project Description

~~The objective of this project is to develop an energy-efficient retrofit HVAC solution that improves air quality while adhering to current government/environmental guidelines to combat COVID-19 and continue to be sustainable in future markets.~~

The objective of this project is to develop and verify an HVAC solution that improves air quality while adhering to current guidelines to combat COVID-19 and continue to sustainable in future markets.

Key Goals

~~The primary goal of this project is to design an efficient HVAC solution that improves air quality and is sustainable for future markets if circumstances change. The team will investigate a variety of technologies and choose to pursue the most promising one. A professional presentation will be given to Trane and FSU representatives to present findings and a proposed solution.~~

The primary goal of this project is to design an energy-efficient HVAC solution that improves air quality and is sustainable for future markets when circumstances change. The solution will adhere to government and environmental guidelines. A variety of technologies will be investigated, and the most promising one will be pursued. The team will verify the usefulness of the chosen solution, and a presentation will be given to Trane and FSU representatives to present findings and offer the proposed solution.

Markets

Due to the increasing threat of the COVID-19 pandemic, air quality management is critical in the effort to the slow of the virus. Any facility that requires ~~proper ventilation to ensure~~ adequate air quality, humidity levels, and comfort is a potential market for this product. The primary markets are Trane and FSU's Utilities and Maintenance Department. Secondary markets include other universities and schools, commercial buildings (hospitals, casinos, offices, bars, schools, restaurants, stadiums, etc.), and residential buildings (homes, nursing homes, apartment complexes, etc.).

Assumptions

The team has assumed that the solution will be ~~retrofit (plug-n-play) for~~ compatible with ~~older~~ existing ~~HVAC~~ systems, which will eliminate the need for new ~~HVAC~~ infrastructure. The solution must adhere to all associated government/environmental guidelines. ~~and fit within the primary market's budget.~~ School facilities may have limited availability or require special guidelines to be followed due to the pandemic. ~~The project budget is based on the school's limited funds.~~ The system will be tested in Florida climate conditions. ~~The system will use existing air-duct designs to circulate and ventilate air throughout the system.~~

The team has assumed that the solution will be compatible with existing systems, which will eliminate the need for new infrastructure. The solution must adhere to all associated government/environmental guidelines. School facilities may have limited availability or require special guidelines to be followed due to the pandemic. The system will be tested in Florida climate conditions.

Stakeholders

The stakeholders associated with this project include our senior design professor, Dr. Shayne McConomy; our advisor, Dr. Juan Ordonez; our sponsor, Trane; our Trane liaison, Cameron Griffith; FSU's Utilities and Maintenance Executive Director, Jim Stephens; and the City of Tallahassee Utilities. The users include indoor facilities that require proper ventilation to ensure adequate air quality, humidity levels, and comfort within the premises. The beneficiaries include those who are susceptible to COVID-19 (elderly, children, individuals with underlying health problems).

1.2 Customer Needs

Questions and Answers:

Question 1: What is currently hindering Trane's HVAC systems in terms of efficiency and air quality?

Answer:

- OEM parts/equipment (York, Carrier, Daikin)
- Costly services

Interpretation: Outsourced equipment and maintenance costs make a large portion of expenses. In house equipment will be used when possible, and maintenance cost will be a consideration.

Question 2: What is expected of our team in terms of building a single component or a complete system?

Answer: The team is expected to satisfy a need, regardless of whether it's through one component or a complete system.

Interpretation: The project will take whatever form is required to achieve its goal.

Question 3: Has Trane made any changes regarding air quality during this COVID-19 pandemic? Can any improvements be made in terms of air quality & if so, how?

Answer: Research and development teams have been working on product testing regarding the different variables associated with the HVAC system (component specifications, component location within the system) to achieve the recommended/optimal humidity levels and IAQ adhering to (ASHRAE, EPA, OSHA) guidelines. New filter technologies including UV germicide filters and bipolar ionization technology are being applied and researched due to these pressing times of the COVID-19 pandemic. An improvement could be made in terms of air quality by increasing the air exchange rate from 4-8 times per hour to something higher (8-10 times per hour?).

Interpretation: The system will improve air quality, and there are many potential methods of doing so.

Question 4: What HVAC components are most prone to failure?

Answer: Depends on the system design and application.

Interpretation: Any component of Trane's HVAC systems is available to be affected by the project.

Question 5: What are the necessary attributes of a Trane HVAC system? (What distinguishes a Trane from a Honeywell?)

Answer: Trane's market consists of ⅓ residential applications and ⅔ commercial applications. The company's driven to provide the lowest life cycle cost, efficient energy usage to reduce carbon emissions, and for sustainability in future markets.

Interpretation: The goals of the project will overlap with the goals of Trane.

Question 6: Will our team's design be focusing more on residential or commercial applications?

Answer: Our team will be focused on air quality and efficiency in facilities like schools and universities.

Interpretation: The project will be designed for use within facilities like schools and universities.

Question 7: Are there any special programs used to design & analyze HVAC systems? Will our team have access to these programs?

Answer: We are free to use any programs for this project, however, we might gain access to Trane's Trace 700 program.

Interpretation: The project is free to use whatever available software that will benefit the design.

Question 8: Who are the stakeholders in this project?

Answer:

- Dr. McConomy - "Technical Buyer"
- Cameron Griffith - Senior Design Mentor (Trane Sponsor) "Executive Buyer"
- Jim Stevens - FSU HVAC Systems Coordinator

Interpretation: The different needs of different types of stakeholders will be met.

Question 9: What government/environmental regulations and guidelines are setting Trane's current product specifications?

Answer: No necessarily enforced regulations (yet), but there are guidelines given by OSHA and the EPA.

Interpretation: Health and safety guidelines will be taken into consideration.

Question 10: What personal customer needs/wants does our team's design need to satisfy?

Answer: The implemented technology must continue to be useful/efficient after the COVID-19 pandemic.

Interpretation: The design will continue to be useful throughout its lifecycle.

Explanation of Results:

The COVID-19 pandemic has made air quality issues more obvious. Our team sat down with project sponsor Cameron Griffith to discuss ways we can help Trane create a practical solution. There are many methods for improving air quality. However, all of them negatively affect system efficiency. Our team is to design a system that maintains excellent air quality without hurting the efficiency of existing HVAC systems. Because air quality and system efficiency are general concerns, not specific to COVID-19, the design will continue to be useful and cost-effective throughout its lifecycle.

1.3 Functional Decomposition

After meeting with our Project sponsor, we were told that the demand for clean building air has never been greater. We learned that many existing HVAC systems are outdated. Many HVAC systems do not exchange the air at a fast-enough rate to keep air from stagnating. Also, we learned that existing advanced particulate filtering solutions are often cost prohibitive to install and service. Based on our interpreted customer needs we divided the project into three systems: Air Quality, Sustainability, and Controls. The first two systems directly satisfy our customers' needs of improving air quality and system efficiency. Our third subsystem is to allow controllability within the HVAC system and to monitor air quality data.

A hierarchical chart (Figure 2, Appendix B) based off of the functional decomposition was created in order to visualize the breakdown of the project's systems. The systems were then expanded upon with desired functions. After creating the hierarchical chart, the systems were then represented within a cross-reference table. This table allows functions to be compared across the different systems for overlap of functionality.

The hierarchical chart illustrates the connection between systems and their functions. The first system we chose was to improve air quality. The customer made it very clear that this is the main priority of the system due to the COVID-19 pandemic. From the interpreted needs, we determined our system needed to be able to clean, dilute, exhaust, and contain indoor air. Being able to clean the air is important to rid the air of contaminants. Diluting the air is necessary to exchange the old air with fresh air. Once the air is exchanged the old air needs to be safely exhausted from the system. Finally, we want the system to contain clean air without leakage. These four functions come directly from Trane; they are essential to good HVAC technology.

The next system identified by the team was to promote sustainability. A big problem with improving air quality is that it typically decreases efficiency. We have been tasked with trying to achieve both to the best of our ability. To promote sustainability within our system, we decided our functions would be to: reduce operating costs, improve system longevity, optimize energy efficiency, and support existing HVAC systems. When dealing with customer applications it is always important to try and reduce installation and running costs. Budgets are often tight and cannot accommodate large renovations. Improving the longevity of the system ensures that the system remains useful in a post-COVID-19 environment. Optimizing energy efficiency vs improved air quality is important. A grossly inefficient system will not result in a useful HVAC system. Furthermore, our design needs to be capable of being retrofit onto existing systems. This is important because it allows many potential use cases in different systems while also being less than the cost of a replacement system. Our sponsor made it clear that practicing sustainable engineering is important to Trane.

Our third system would be the controls aspect of the project. By monitoring certain variables within the system, it allows the system to be more dynamic. It is important that the system can respond to changing conditions. The functions identified were: maintain recommended humidity levels and CO2 levels, a comfortable temperature, and monitor volatile organic compounds (VOCs). It is important to maintain a humidity level that promotes both the comfort of the inhabitants and the reduced growth of bacteria. Elevated CO2 levels can be harmful and uncomfortable. A basic yet important function is that the system should maintain a comfortable temperature. If an HVAC system cannot keep the building comfortable, then it has failed its most basic duty. It is important to monitor and remove VOCs within the system as inhabitants can inhale them and become sick. These four functions enable control of system to the degree necessary to maintain air quality and promote sustainability.

The hierarchy chart was used to determine our basic functions. The cross-reference chart is used to illustrate that some of these functions contribute to multiple sub-systems. Most of the control functions are directly related to air quality. Maintaining humidity level is a function of controls but is integral to air quality. The functional decomposition gives a better understanding of the project by defining the relationships between each function. This understanding is useful for concept generation and selection. The function resolution achieved in our functional decomposition was defined well enough to convey the necessary design without constraining certain aspects.

Systems	Air Quality	Sustainability	Controls
Functions			
Maintain recommended humidity levels	X		X
Maintain recommended CO2 levels	X		X
Maintain comfortable temperature			X
Monitor VOCs	X		X
Minimize operating costs		X	X
Improve system longevity		X	
Optimize energy efficiency		X	X
Support existing HVAC systems		X	
Clean indoor air	X		
Dilute indoor air	X		
Exhaust indoor air	X		
Contain indoor air	X		X

Table 1. Cross-Reference Chart

The functional decomposition illustrates what the project must accomplish fundamentally. No matter what form it takes, the final project will be a controlled system that improves air quality and promotes sustainability.

1.4 Target Summary

After defining the functions of the project in the function decomposition, methods for defining and measuring those functions were examined.

There are four critical targets. If these four targets are met, the project will be a success. Many of the other targets relate to these. A VOC concentration of 0.3 milligrams per cubic meter is defined by the CDC as harmless air. There are conflicting data on this number. Erring on the side of caution, 0.3 is on the lower end of recommended values (a lower concentration is better). Air changes per hour (ACH) is how often the inside air is entirely exchanged for fresh air. The CDC recommends different values based on the room in question. For example, chemical facilities have higher recommended ACH than grocery stores. 10 ACH is on the high end for applications for facilities like schools and office buildings. Energy usage and operating costs are defined as a percentage of the value of the pre-existing system. When the project is implemented into existing systems, energy usage will unavoidably increase, but a minimal increase is desired. 115% percent energy usage represents a 15% increase in energy use. This is an intermediate value based on other air quality solutions. Operating costs directly related to energy use, but also includes additional maintenance expenses on the additional system component. The desired operating costs of the augmented system is 120% that of the existing system. These metrics are defined so that they scale with the size of the existing system. The following table shows the critical targets and metrics with their functions.

Function:	Target:	Metric:
Dilute Indoor Air	10	ACH
Clean Indoor Air	0.3	VOC Concentration (mg/m^3)
Minimize Operating Costs	120%	Current Costs (%)
Optimize Energy-Efficiency	115%	Current Usage (%)

Table 2. Critical Targets Summary Table

Other, noncritical functions are defined by the current guidelines for HVAC systems in the United States. These standards are used because existing systems are already tested based on them. The metrics are CO2 concentration, humidity control, and temperature control. The functionality of the existing system must be unaffected by the implementation of the project.

There are two other functions that are also measured by ACH. Diluting the indoor air directly means bringing in fresh air but exhausting and containing the air play an important role as well. Each of them contributes uniquely to increasing ACH.

A table detailing each function with its respective metric and target can be found in Appendix C.

Other needs are represented in these targets. It's important that the project promotes the ideals Trane uses to represent itself. Minimizing maintenance cost, and thus operating cost, conveys a robust design with a long lifecycle. Minimizing energy usage connects to an environmentally friendly mindset. Less energy usage means less carbon emissions. Notably, none of the targets and metrics specifically mention COVID. To be a sound economic investment, the system needs to be useful independent of COVID. Decreasing the VOC concentration without a substantial increase in energy usage will always be an attractive feature.

If the critical metrics are measured, the project can be successfully validated. Testing for energy usage is simple. Measuring the energy usage of the implemented design and comparing it to the usage of the subject HVAC system gives all the necessary information. It is common practice to estimate maintenance cost as a fraction of the initial cost a system. With this estimate and energy usage, operating costs is easily calculated. ACH is just a function of the size of the facility and the volumetric flow rate of the system, which can be measured in any number of ways. Measuring the total VOC concentration is more difficult, as there are a variety of chemical compounds that are identified as VOCs. To measure this accurately, a specialized device is required. Due to limited resources, the device would have to be provided either by the college or by Trane.

Many of these targets were determined from the functional decomposition and the customer needs. Each one of these targets has an associated metric as to how to determine if the targets are met. These metrics were determined largely through group research. For targets related to air quality composition, the associated metric was found by consulting industry standards set by ASHRAE and other regulatory agencies (EPA, OSHA, WHO). The installation cost was found as the desired metric for fitting the HVAC system because the system should require little to no modifications to be implemented. Optimizing energy efficiency was expressed as a percentage as this function will scale with the size of the HVAC system. The energy usage will increase for larger HVAC systems as they are used to cool larger areas. This same concept explains why the operating costs were expressed as a percentage as well. This percentage was larger than the energy efficiency as it must account for maintenance of the system as well as energy usage.

1.5 Concept Generation

Methodology

There are many ways to approach improving air quality, which, fundamentally, the goal of the project. There are any number of ways to fill a space with cleaner air. Air can be directly cleaned. Indoor air can be diluted with fresh outdoor air. Many systems underperform to conserve energy. Improvements in energy efficiency can lead to improved air quality without increased energy expenditure. Energy can be found elsewhere and applied in a similar way.

As a result, there is no shortage of usable concepts. Many were provided as recommendations from organizations like the CDC and ASHRAE. Some were offered as interesting possibilities by Trane, and some are very minor changes to existing technology.

Most of the concepts came naturally, but the Crap Shoot method was also used. Everyone is affected by air quality, and any indoor activity is as well. There are plenty of resources to draw on to clean air. Because of this widespread, the Crap Shoot method seemed particularly useful. Almost every possible combination resulted in a usable concept.

Furthermore, most air quality technologies are additive, so any number of them can be used together. Solar panels can offset the energy usage of UV lights. UV lights can be used in conjunction with high quality filters in particularly vulnerable areas. This lends itself to a morphological chart, but because almost any solution can be combined with almost any other solution, it wasn't used.

The following concepts were chosen as the most promising. A summary is given of each. They are further compared in Concept Selection. All generated concepts can be found in Appendix D.

Medium Fidelity Concepts:

Concept 80. Implement antimicrobial coated duct lining to inhibit mold growth within the ductwork and to make duct cleaning more feasible.

Assuming the current system duct lining installed, the inclusion of antimicrobial duct lining would improve the system. The lining acts as an insulator which reduces energy consumption and prevents unwanted water damage which can lead to costly damages. Adding duct lining to an HVAC system also improves airflow by sealing any holes within the duct and increases air quality if the lining is antimicrobial.

Concept 29: Implement Photo Hydro Ionization (PHI) as a purification technique to increase air quality and reduce ozone levels.

An alternative purification technology developed by RFG Environmental Group is photo hydro ionization (PHI). This technology utilizes UV lights and a catalyst to create hydro-peroxide ions to deactivate harmful aerosols. During preliminary testing by Kansas State University, PHI was proven effective against viruses and bacteria such as MRSA and Swine Flu.

Concept 91: Implement Photocatalytic Oxidation (PCO) as a filtration technology.

This filtration technology is analogous to a catalytic converter in automobiles, it is a promising technology that uses high-intensity UV-C lights to radiate a titanium dioxide or quad metal catalyst (as in PHI). As a result, a hydroxyl radical field is developed. These hydroxyl radicals are powerful oxidizers that oxidize carbon-based molecules and microorganisms in the air.

Concept 1: Increase the ACH by increasing the speed of the induction fan motors to dilute the indoor air with more fresh outdoor air.

Increasing the air exchange rate per hour (ACH) is one of the simplest ways to improve air quality, given that the outdoor air is satisfactory. To do this, the speed of the induction fan motors for both intake and exhaust must be increased using a variable frequency drive. By increasing the ACH the indoor air is further diluted by the incoming fresh outdoor air. This dilution reduces the harmful aerosols and particulate matter concentration indoors, effectively improving air quality.

Concept 64: Install Internet of Things (IoT) systems in critical buildings to increase preventative maintenance by sensing data on air quality and equipment status

The future of HVAC is essentially a fully integrated system called Internet of Things (IoT) embedded with sensors, software, and connected devices. This smart system can track data to increase the system's efficiency and ultimately run autonomously. The end-user has very few responsibilities due to the seamless operation of the system. By tracking data with sensors and displaying component states, the end-user can perform maintenance when necessary. The integration of this technology requires advanced machine learning algorithms to identify a particular building's requirements and schedules, which along with the sensors prove to be very costly.

High Fidelity Concepts:

Using geothermal energy to augment or power an HVAC system isn't new technology, but it isn't widely used. The temperature of the earth is fairly consistent after a certain depth. By burying a heat exchanger at a depth where the temperature is uniformly moderate, a house can be cooled in the summer and heated in the winter. For a large, horizontal heat exchanger, it only needs to be buried about two meters deep.

Geothermal heat exchangers have become popular options for ecological minded residential applications. Rather than using natural gas or electricity to condition air, a single pump is needed to flow water through the buried heat exchanger.

In the case of large commercial buildings, it's possible the demands would overcome the supply a geothermal system creates. Even in this case, there are savings to be made by augmenting a traditional HVAC system with a geothermal one. This is especially notable if the system needs to be run all the time, with peaks in troughs in demand. During such troughs, the geothermal system could provide all the required energy, and during peaks the traditional system can fill in the rest.

Note, this type of system is different from a geothermal powerplant. These plants dig thousands of feet to where the earth is extremely hot and use that energy to generate steam to create electricity. The scaled down version of that technology considered for HVAC purposes does not generate electricity. (Concept 13)

The use of better filters is an unexciting but very likely solution to most air quality issues. There are many advantages to this solution. Notably, most systems don't need to be modified for higher quality filters. This factor cannot be over emphasized. It represents huge savings in both money and time. No required modification to the existing system obviously saves money, but modifications also take time. Many institutions are trying to get people back indoors as quickly as possible. This solution can be implemented over a weekend.

They are also scalable to whatever air quality issues are prevalent. MERV 13 filters and above are at least somewhat effective against most airborne VOCs. Above that, they become increasing effective. Areas that are particularly vulnerable can be fitted with higher quality filters without any more investment than a higher rated filter. This greatly simplifies the solution for facilities with varying buildings or systems. An example is Florida States' campus, where every building was built differently with a different HVAC system at a different time. Research labs can be fit with MERV 18 while general lecture halls can be fitted with a lower rated filter, but the work and time put in are the same.

Furthermore, these filters don't require any extra dilution of the indoor air. This means no additional heating or dehumidification needed. The system should function almost exactly as it did with the old filters.

However, higher quality filters to result in a higher pressure drop, and this can strain some systems. Old systems fit with high rated filters can struggle or stall under the increased load. Newer system won't frequently struggle with this. Regardless, the system has to work harder to overcome the increased pressure drop. This does result in an increase in power draw, but it's difficult to say whether it is significant or not. The major cost incurred with this solution is the upfront cost of the filters. (Concept 26)

Bipolar ionization is a newer technology. As such, there are conflicting data and claims as to its uses and effectiveness. There is little scientific, peer-reviewed literature on the subject. If this is the chosen solution, testing will be a much more significant part of the project. However, it is potentially extremely effective solution.

It works by applying a charge to molecules in the air, both negative and positive. These ions allow for groups of molecules and particles to gather and collect. These conglomerations of small particles can become large enough to be caught in filters or heavy enough to fall to the ground. Either way, the particles are removed from the air. The ionized molecules also react with viruses, bacteria, and mold in the air, killing them. So, the technology works to filter the air as well as neutralize harmful organic particulate.

Bipolar ionization systems aren't very expensive to install, but a very high voltage is required to create the ionized molecules. It's unclear to what degree this would affect energy consumption of a system.

Compared to other air quality solutions, bipolar ionization most directly affects the concentration of viruses in the air, making it a prominent contender for combatting COVID. (Concept 10)

1.6 Concept Selection

House of Quality

The identified customer needs were tied to specific engineering characteristics in the house of quality shown in Table 3. These characteristics include mass, energy consumption, flow rate, contaminant concentration, & installation cost. A rating was given for each characteristic depending on the influence it has on each customer requirement. These ratings were summed and then multiplied by the importance weight factor found in the binary pairwise comparison, located in appendix E. The relative weight for each customer need was found and ranked. The results of the house of quality show that flow rate is the priority engineering characteristic followed by, contaminant concentration, energy consumption, installation cost, & mass.

House of Quality						
Engineering Characteristics						
Improvement Direction		↓	↓	↑	↓	↓
Units		kg	kW	m^3/s	ppm	USD
Customer Requirements	Importance Weight Factor	Mass	Energy Consumption	Flow Rate	Contaminant Concentration	Installation cost
1. Air Quality	**4**		3	9	9	
2. Longevity	**1**			9	9	
3. Energy Efficiency	**2**		9	3		
4. Total Cost	**1**					9
5. Retrofit	**2**	3				9
Raw Score	**159**	6	30	51	45	27
Relative Weight %		0.038	0.189	0.321	0.283	0.170
Rank Order		5	3	1	2	4

Table 3: House of Quality

AHP

From the AHP, it became apparent that combatting COVID was an important factor in the analysis of each concept. Air quality was clearly the most heavily favored factor, followed by energy consumption and being a retrofit design. Total cost and system longevity were weighted the lowest. The comparison was normalized for ease of use.

Pairwise Comparison - Normalized						
	1	2	3	4	5	Criteria Weight
1. Air Quality	0.639	0.446	0.369	0.443	0.620	0.503
2. Longevity	0.071	0.050	0.025	0.246	0.013	0.081
3. Energy Efficiency	0.128	0.149	0.074	0.246	0.013	0.122
4. Total Cost	0.071	0.010	0.015	0.049	0.266	0.082
5. Retrofit	0.091	0.347	0.517	0.016	0.089	0.212
Total	1	1	1	1	1	1

Table 4. Normalize Pairwise Comparison

Air quality directly reflects the effectiveness of the design. If high air quality is achieved, the design is successful. Other factors change the degree of that success, but this is clearly the primary goal of the project.

A retrofit design reflects in the total cost, but also the time for installation. This is important for commercial buildings trying to get people back to work, or schools trying to get people back to class. Some design, like high quality filters, can be installed over the weekend. Other designs require significantly more time and resources to put in place. This could be a limiting factor if schools are resuming class.

Energy consumption represents operation costs to the consumer. Some concepts would result in increases in energy consumption by at least an order of magnitude. These designs frequently worked well in cleaning the air, but aren't sustainable environmentally or economically.

Total cost and system longevity are both important factors to the design, but less important to its overall success. They both reflect the economic investment in the design, which is obviously important to the consumer, but only if the system functions properly in the first place.

Pugh Matrices

The first Pugh chart compares the five medium and three high fidelity concepts selected with a baseline datum solution. The datum represents the current HVAC solution used by FSU. From the chart it can be seen that many concepts were very close in their rankings of pluses and minuses. The four best performing concepts were compared with a new pugh chart.

Pugh Matrix - 1									
		Concepts							
Engineering Characteristics		1	2	3	4	5	6	7	8
Mass	Datum	+	+	+	+	+	-	S	+
Energy Consumption		+	+	+	-	+	+	+	+
Flow Rate		-	-	-	+	-	+	-	-
Contaminant Concentration		+	+	+	+	+	+	+	+
Installation cost		+	-	-	+	+	-	+	+
# of pluses		4	3	3	4	4	3	3	4
# of minuses		1	2	2	1	1	2	1	1

Table 5: Pugh Matrix - 1

To better compare them, a new datum was chosen. Concept 2, photo-hydro ionization, was chosen because it was one of the concepts that represented a good baseline of positives and negatives. Concepts 3, 6, and 7 were eliminated due to their mediocre performance. This new datum was tabulated into Table 4 below. Concept 8 compared slightly better than the other remaining concepts.

Pugh Matrix - 2					
		Concepts			
Engineering Characteristics		1	4	5	8
Mass	Datum Concept 2	+	+	+	+
Energy Consumption		+	-	+	+
Flow Rate		-	+	+	+
Contaminant Concentration		+	+	+	+
Installation cost		+	+	-	+
# of pluses		4	4	4	5
# of minuses		1	1	1	0

Table 6: Pugh Matrix - 2

Final Selection

After the selection process, bipolar ionization is left as the final concept. It was concept 10 in Concept Generation, and Concept 8 in Selection. The process works to both filter the air and kill harmful suspended organics. It uses a high voltage to create charged molecules in the air. These ions react with and neutralize bacteria, mold, and viruses directly. They also attract clumps of particulate that are large enough to be easily removed from the air.

From the house of quality, it was determined that flow rate is the most important characteristic, with contaminant concentration closely second. While bipolar ionization doesn't increase flow rate, it only slightly hinders it. It's also notably good at reducing the contaminant concentration.

There weren’t many concepts that so directly neutralize viruses in the air. Combined with comparatively easy installation, that makes bipolar ionization a reasonable candidate for combatting COVID. These were two heavily weighted factors that this concept excelled in. This can be seen in table 6, the second Pugh matrix.

All tables can be found in Appendix E.

1.8 Spring Project Plan

Chapter Two: EML 4552C

2.1 Spring Plan

Project Plan.

Build Plan.

Appendices

Appendix A: Code of Conduct

Mission Statement

~~Improve the air quality and efficiency of a Trane HVAC system and do so safely and responsibly.~~ ~~Improve the health and safety of the public through means of properly cleaning indoor air during the COVID-19 pandemic and beyond.~~

~~Provide a sustainable method for cleaning indoor air to ensureimprove protect the health and safety of the public during the COVID-19 pandemic and beyond.~~

Provide a method of combating COVID-19 by improving air quality to promote public health and safety.

Team Roles

- Jake Hamilton - *Design Engineer*
  - The Design Engineer will be responsible for most mechanical design aspects as well as design review. Responsibilities include creating design drafts, performing design calculations, and overseeing the design process.
- Nicholas Holm - *Environmental Engineer*
  - The Environmental Engineer will be responsible for ensuring design and implementation meets environmental standards. Tasked with researching best practices and guidelines relating to health and safety of HVAC design.
- Andi Santeiro - *Quality Control Engineer*
  - The Quality Control Engineer will be in charge of testing, and managing the materials. Making sure everything is running smoothly. Responsibilities include

running tests using a select group of programs, as well as analyzing all materials used throughout the project.

- Joseph Thyer - *Project Manager*
  - The Project Manager will manage communication between group members and project stakeholders, keep track of project budget and timelines, and finalize and submit all assignments.
- Gavin Young - *Fluids Engineer*
  - The Fluids Engineer will be responsible for most thermal fluids calculations relating to heat transfer, fluid mechanics, and thermodynamics of the system. Also responsible for the design of thermal fluid components within the system.

Team roles were assigned based on experience and abilities. Role changes and role responsibilities will be discussed during Zoom meetings or through our Discord server. Roles will be set; however, adjustments can be made if all group members are notified and come to an agreement. Group members must be notified within 48 hours of possible role change.

Communication

The group will discuss time availability and share general work schedules. Changes in availability can be discussed during the weekly scheduled meetings. We will meet primarily through Zoom and Discord. Correspondence will be done via email. Physical meetings will be limited as much as possible. If physical meetings become necessary, we will strive to conduct them safely and responsibly. Group members will be expected to respond to messages within 12 hours.

Dress Code

Client Zoom or video meetings will be business casual, requiring pants and a polo or button-down shirt. If the client indicates a different preferred dress code, changes will be made accordingly. Group presentations will be business casual, requiring pants and a polo or button-down shirt. Members will coordinate at least 24 hours before the scheduled meeting to decide on a cohesive appearance.

Attendance Policy

We will meet weekly every Tuesday after class from 7:45 PM - 8:45 PM (or starting when class ends and ending when needed) for weekly progress reports and to discuss future mission-critical project tasks. Additionally, there will be an optional meeting every Thursday from 7:45 PM - 8:45 PM to discuss project objectives. Meetings with sponsors and advisors will be scheduled as needed and will be held via Zoom or Discord.

Attendance will be mandatory for mission-critical group meetings and weekly progress report meetings. If a group member is unable to attend a meeting, he/she is expected to notify the group at least 24 hours in advance.

The project manager will record attendance. If a group member continually misses meetings, it will be discussed with the group. If it continues to be a problem, the Senior Design Advisor will be contacted.

Statement of Understanding

I hereby acknowledge that I have read the above Code of Conduct and agree to abide by the rules and regulations established for this group.

Signatures:

Jake Hamilton

Nicholas Holm

Andi Santeiro

Joseph Thyer

Gavin Young

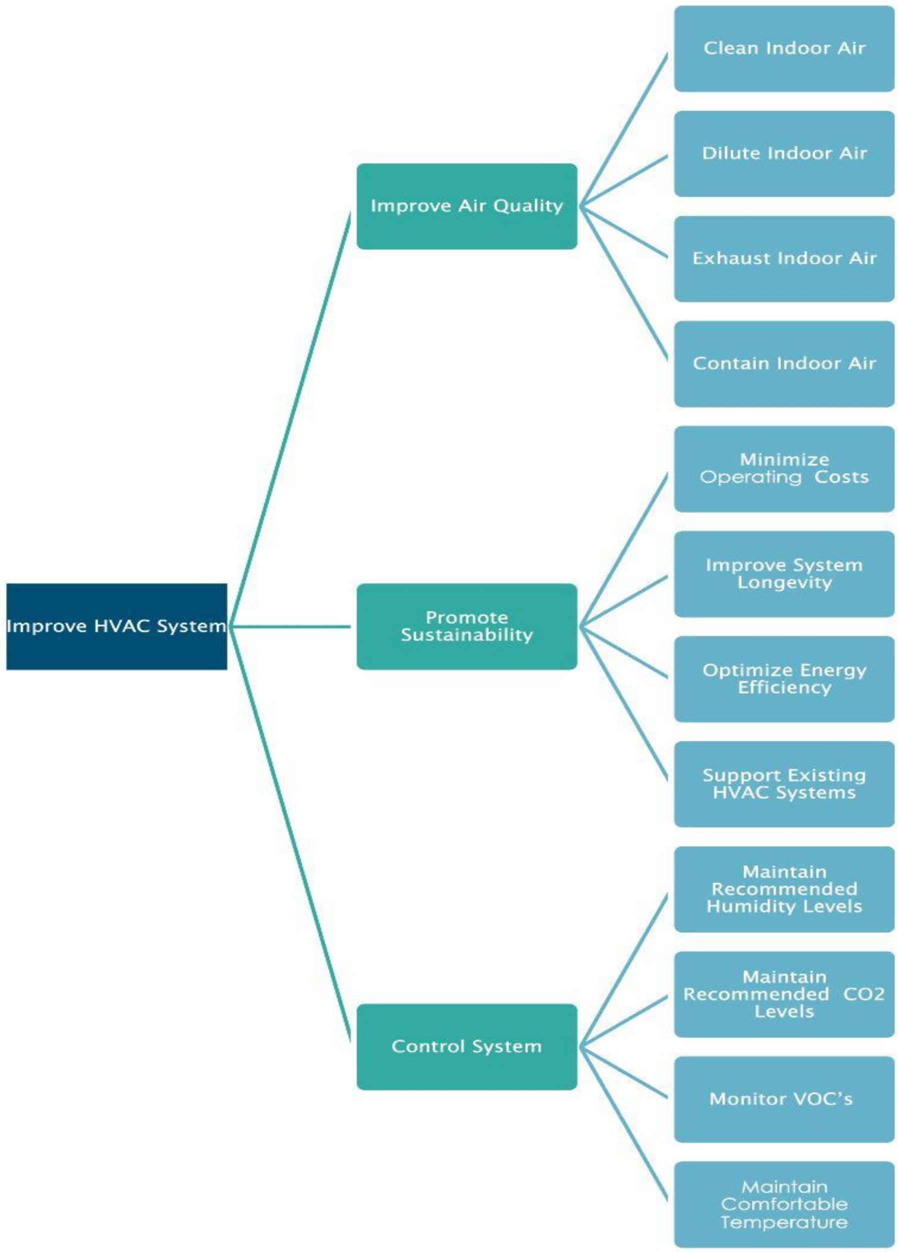
Appendix B: Functional Decomposition

Figure 1. Work Breakdown Structure

Milestone #:	Tasks:	Sub-Tasks:	Assigned to:
1	Project Scope		
		1.1 Project Description	Andi
		1.2 Key Goals	Nicholas
		1.3 Primary Market	Jake
		1.4 Secondary Market	Gavin
		1.5 Stakeholders	Joseph
		1.6 Assumptions	Jake
		1.7 Write Document	Nicholas
		1.8 Review Document	Joseph
		1.9 Submit Document	Joseph
2	Work Breakdown Structure		
		2.1 Tabulate Tasks in Descending Order	Jake
		2.2 Assign Each Task to a Resource	Gavin
		2.3 Write Document	Nicholas
		2.4 Review Document	Joseph
		2.5 Submit Document	Joseph
3	Customer Needs		
		3.1 Research HVAC system components	Jake
		3.2 Gather Customer Data	Nicholas
		3.3 Synthesize Customer Data	Andi
		3.4 Organize Customer Needs	Joseph
		3.5 Establish Relative Importance of Needs	Gavin
		3.6 Reflect on Results	Andi
		3.7 Write Document	Nicholas
		3.8 Review Document	Joseph
		3.9 Submit Document	Joseph
4	Functional Decomposition		
		4.1 Research Patents & Regulations on HVAC	Nicholas
		4.2 Describe Physical Action	Jake
		4.3 Describe Outcome	Gavin
		4.4 Break Down Project into Units	Andi
		4.5 Write Document	Andi
		4.6 Review Document	Joseph
		4.7 Submit Document	Joseph
5	Targets and Metrics		
		5.1 Perform Benchmarking on Existing Products	Jake
		5.2 Identify Product Requirements & Restraints	Andi
		5.3 Assign Metrics to be used in Validation	Gavin
		5.4 Assign Specific Targets to each Goal	Jake
		5.5 Write Document	Nicholas
		5.6 Review Document	Joseph
		5.7 Submit Document	Joseph
6	Virtual Design Review #1		
		6.1 Make Presentation	Jake
		6.2 Review Presentation	Andi

		6.3 Practice Presentation	Joseph
		6.4 Submit Presentation	Joseph
		6.5 Give Presentation	Joseph
7	Concept Generation & Selection		
		7.1 Set Meeting	Jake
		7.2 Generate Concepts	Andi
		7.3 Risk Assessment	Nicholas
		7.4 Narrow Down Concepts	Joseph
		7.5 Select Final Concept	Gavin
		7.6 Review Document	Joseph
		7.7 Submit Document	Joseph
8	Virtual Design Review #2		
		8.1 Make Presentation	Nicholas
		8.2 Review Presentation	Gavin
		8.3 Practice Presentation	Joseph
		8.4 Submit Presentation	Joseph
		8.5 Give Presentation	Joseph
9	Virtual Design Review #3		
		9.1 Make Presentation	Andi
		9.2 Review Presentation	Gavin
		9.3 Practice Presentation	Nicholas
		9.4 Submit Presentation	Joseph
		9.5 Give Presentation	Joseph
10	Create Spring Project Plan		
		10.1 Outline Objectives	Jake
		10.2 Create Timeline	Nicholas
		10.3 Assign Objectives to Team Members	Andi
		10.4 Review Document	Joseph
		10.5 Submit Document	Joseph
11	Evidence Manual		
		11.1 Abstract	Nicholas
		11.2 Disclaimer	Jake
		11.3 Appendices	Gavin
		11.4 Assemble Document	Andi
		11.5 Review Document	Joseph
		11.6 Submit Document	Joseph

Figure 2. Hierarchical Chart


Improve HVAC System
Improve Air Quality
Promote Sustainability
Control System
Clean Indoor Air
Dilute Indoor Air
Exhaust Indoor Air
Contain Indoor Air
Minimize Operating Costs
Improve System Longevity
Optimize Energy Efficiency
Support Existing HVAC Systems
Maintain Recommended Humidity Levels
Maintain Recommended CO2 Levels
Monitor VOC's
Maintain Comfortable Temperature

Appendix C: Target Catalog

Table 1: Target Catalog Table

Function:	Target:	Metric:
Dilute Indoor Air	10	ACH
Contain Indoor Air	10	ACH
Exhaust Indoor Air	10	ACH
Clean Indoor Air	0.3	VOC Concentration (mg/m^3)
Maintain VOC Concentration	0.3	VOC Concentration (mg/m^3)
Control CO2 Concentration	1000	ppm CO2
Control Humidity Level	45-55	%Humidity
Control Temperature	24-26	°C
Minimize Operating Costs	120%	Current Costs (%)
Optimize Energy-Efficiency	115%	Current Usage (%)

Appendix D: Concept Generation

Generated Concepts

Concept 1. Increase the ACH by increasing the speed of the induction fan motors to dilute the indoor air with more fresh outdoor air.

Concept 2. Install independent purification filters in the ductwork before the systems air reaches the occupied space, these can potentially be powered by energy recovery. (solar, geothermal, gym equipment, ect.)

Concept 3. Improve the current COVID alterations by utilizing existing vacancy sensors to also control fan speed for different degrees of air ventilation rate

Concept 4. Decrease energy usage by consistently cleaning heating/cooling coils.

Concept 5. Explore alternative refrigerant choice to minimize the use of ozone-depleting substances which will reduce carbon emissions and increase efficiency

Concept 6. Implementing indoor gardens to increase air quality

Concept 7. Place window exhaust units in buildings to remove contaminated air

Concept 8. Increase the use of open windows for natural ventilation

Concept 9. Have containers that capture and retain fresh air

Concept 10. Utilize bipolar ionization through HVAC mounted ionizers

Concept 11. Become robots that don't breathe air

Concept 12. Place portable air purifiers in classrooms

Concept 13. Direct plumbing underground to a depth with cooler temperatures to use less energy to cool fluids. (Geothermal Heating and Cooling)

Concept 14. Increase cleaning standards to remove dust and other pollutants from the buildings

Concept 15. Use excess energy from fitness centers to power UVC germicide filters within the ductwork

Concept 16. Run pipes under the Leach gym pool to be used as a heat exchanger

Concept 17. Start an indoor air quality health club at FSU

Concept 18. Open windows in classrooms to let in fresh air

Concept 19. Continue classes online to reduce student exposure

Concept 20. Enforce the Tobacco-Free Campus to include electronic vaporizers inside classrooms that emit harmful chemicals

Concept 21. Increase humidity and heat in classrooms as Covid-19 does not survive as well in these conditions.

Concept 22. Conduct classes outdoors

Concept 23. Wear hazmat suits in classrooms

Concept 24. Contact trace ill students and quarantine possible infected students

Concept 25. Temperature check every individual before coming into class

Concept 26. Upgrade filters from MERV 13 to either MERV (14-16) or HEPA and calculate the associated theoretical pressure drop and energy consumption.

Concept 27. Clean all existing HVAC equipment to remove mold and pollutants

Concept 28. Remove sources of pollutants at air intake locations

Concept 29. Implement Photo Hydro Ionization (PHI) as a purification technique to increase air quality and reduce ozone levels

Concept 30. Seal up leaks and deficiencies in existing buildings

Concept 31. Integrate a streamlined ductwork system to achieve a maximum indoor air ventilation rate

Concept 32. Examine food storage standards at FSU mess halls to avoid pollutant producing pests

Concept 33. Put fans in classrooms to lower temperatures while using less energy

Concept 34. Limit room capacity to reduce heat in rooms

Concept 35. Increase the radius of no-smoking zones around the campus buildings

Concept 36. Provide student and staff training on managing indoor air quality

Concept 37. Provide a PSA to surroundings residents on ways to improve IAQ within their homes and businesses

Concept 38. Increase MERV filter rating to 13+ while increasing the AHU's fan motor speed to accommodate 10 ACH depending on the state of the vacancy sensor

Concept 39. Substitute the fan blade material for a lighter one, decreasing the power necessary to turn the fan

Concept 40. Implement a strict filter cleaning regiment to ensure maximum system airflow

Concept 41. Replace surfaces on classroom objects with more sterile materials

Concept 42. Substitute paint and carpets that emit harmful VOC's into the occupied space with sterile materials

Concept 43. Introduce MERV filters at the room vent level for increased filtration

Concept 44. Hire a routine cleaning service to disinfect areas

Concept 45. Use activated charcoal in combination with HEPA grade filters to diminish system contaminants

Concept 46. Use integrated solar panels to power auxiliary devices for the system to reduce the load on primary components (coils, fans)

Concept 47. Use the desiccant wheel to improve system efficiency

Concept 48. Use light fan blades to increase energy efficiency (concept 39)

Concept 49. Replace outdated fan drives with variable frequency drives to ensure accurate fan speed for different ventilation rate requirements

Concept 50. Exhaust hotspots like restrooms continuously

Concept 51. Implement the Trane Catalytic Air Cleaning System (TCACS) to utilize a combination of air cleaning technologies

Concept 52. Add thermal diffusers to rooms to utilize the benefits of VAV systems without the cost

Concept 53. Consider running the HVAC system at maximum outside airflow for 2 hours before and after spaces are occupied, in accordance with manufactory recommendations.

Concept 54. Disable Demand-Control Ventilation (DCV) to keep outdoor airflow at design occupancy levels and ultimately improve dilution

Concept 55. Coat key surfaces with antimicrobial soil-resistant (AMSR) coating to reduce bacteria, mold, and rust from forming

Concept 56. Introduce CO2 air scrubbers into places with high traffic and low air exchange rate.

Concept 57. Substitute V belts with direct couplers from the electric motor to the fans to reduce particulate debris accumulation within the system

Concept 58. Integrate WiFi/Bluetooth occupancy sensors to control the systems ventilation rate

Concept 59. Implement a filter replacement/check maintenance program to periodically ensure that there is a clean filter that properly fits each air handler

Concept 60. Upgrade the CO2 sensors in the Dirac library to accurately record higher CO2 concentrations (2000+ ppm) and couple it with the system

Concept 61. Add a carbon capture chamber into the HVAC system using solid amine sorbents

Concept 62. Add more windows in the Dirac library and utilize natural ventilation when permittable

Concept 63. Perform thorough duct inspection to mitigate mold growth and check for system leaks

Concept 64. Install the Internet of Things (IoT) systems in critical buildings to increase preventative maintenance by sensing data on air quality and equipment status

Concept 65. Add or improve upon insulation to existing HVAC ducts to better trap energy within the airflow to maintain temperature and humidity levels.

Concept 66. Research alternative refrigerants and expansion devices to remain sustainable after the inevitable R22 ban

Concept 67. Implement an artificial intelligence controller to vary HVAC demand based on building parameters and pedestrian traffic

Concept 68. Synchronize class schedules to minimize output times for the HVAC system.

Concept 69. Implement higher quality air filters

Concept 70. Implement a central dehumidification system in older buildings that are prone to mold growth.

Concept 71. Ensure all vents are not obstructed by furniture or equipment to maintain the maximum flow rate.

Concept 72. Periodically hire an indoor air quality specialist to evaluate the air.

Concept 73. Develop a thorough maintenance schedule to perform preventative maintenance before issues arise.

Concept 74. Limit building occupancy to a minimum.

Concept 75. Use only Trane products, because they are superior in quality

Concept 76. Place shoe cleaning mats at entrances to prevent dirt and pollutants from being deposited deeper inside the building.

Concept 77. Place activated charcoal bags at locations with poor air quality.

Concept 78. Reduce the use of harmful pesticides around campus. The chemicals release VOCs that can travel into the HVAC system

Concept 79. Use a stand-alone ductless system in highly contaminated areas in conjunction with the existing fixed duct system

Concept 80. Implement antimicrobial coated duct lining to inhibit mold growth within the ductwork and to make duct cleaning more feasible

Concept 81. Utilize AirNow's Air Quality Flag Program to inform the public the EPA's AQI and coordinate personnel activities accordingly

Concept 82. Implement a secondary natural ventilation system driven by either buoyancy or wind

Concept 83. Replace existing heat pumps with electrocaloric cooling alternatives. Reduces greenhouse gas emissions from the system.

Concept 84. Renovate buildings with building-integrated heat and moisture exchangers built into walls. This system will work in conjunction with the HVAC system to condition the indoor air

Concept 85. Perform routine checks on the chiller system piping to ensure no working fluid is leaking IAQ concerns associated with water chillers involve the potential release of the working fluids from the chiller system

Concept 86. Use Vaporized Hydrogen Peroxide (H2O2) to fill a space to disinfect the air and surfaces while the building is unoccupied

Concept 87. Implement needle-point bipolar ionization to improve air quality

Concept 88. Use Duct Sealing to Avoid Duct Leakage to save energy

Concept 89. Utilize thermal energy from the Sun to power auxiliary portable air purifiers throughout FSU's campus

Concept 90. Continue the mask requirements

Concept 91. Implement Photocatalytic Oxidation (PCO) as a filtration technology

Concept 92. Ice powered air conditioning

Concept 93. Add cryogenic heat exchangers to improve efficiency

Concept 94. Focus on teaching horticulture within the college of engineering to grow plants to clean the air.

Concept 95. Supply each student with an oxygen tank

Concept 96. Harness heat from the computer lab

Concept 97. Open a floriculture college

Concept 98. Store all VOC outgassing materials and substances outside

Concept 99. Irradiate the air in the air handler to kill viruses.

Concept 100. Remove all carpeting from all buildings.

Appendix E: Concept Selection

Legend	
1	Antimicrobial Coating
2	PHI
3	PCO
4	ACH
5	IoT
6	Geothermal
7	Filters
8	Ionization

Table 1E. Concept Legend

House of Quality						
Engineering Characteristics						
Improvement Direction		↓	↓	↑	↓	↓
Units		kg	kW	m^3/s	ppm	USD
Customer Requirements	Importance Weight Factor	Mass	Energy Consumption	Flow Rate	Contaminant Concentration	Installation cost
1. Air Quality	**4**		3	9	9	
2. Longevity	**1**			9	9	
3. Energy Efficiency	**2**		9	3		
4. Total Cost	**1**					9
5. Retrofit	**2**	3				9
Raw Score	**159**	6	30	51	45	27
Relative Weight %		0.038	0.189	0.321	0.283	0.170
Rank Order		5	3	1	2	4

Table 2E. House of Quality

Binary Pairwise Comparison						
	1	**2**	**3**	**4**	**5**	**Total**
1. Air Quality	-	1	1	1	1	4
2. Longevity	0	-	0	1	0	1
3. Energy Efficiency	0	1	-	1	0	2
4. Total Cost	0	0	0	-	1	1
5. Retrofit	0	1	1	0	-	2
Total	0	3	2	4	1	10

Table 3E. Binary Pairwise Comparison

Pairwise Comparison						
	1	**2**	**3**	**4**	**5**	**Total**
1. Air Quality	1	9	5	9	7	31.0
2. Longevity	0.111	1	0.333	5	0.143	6.59
3. Energy Efficiency	0.200	3	1	5	0.143	9.34
4. Total Cost	0.111	0.20	0.200	1	3.000	4.51
5. Retrofit	0.143	7.00	7	0.333	1	15.5
Total	1.57	20.2	13.5	20.3	11.3	

Table 4E. Pairwise Comparison

Pairwise Comparison - Normalized						
	1	2	3	4	5	Criteria Weight
1. Air Quality	0.639	0.446	0.369	0.443	0.620	0.503
2. Longevity	0.071	0.050	0.025	0.246	0.013	0.081
3. Energy Efficiency	0.128	0.149	0.074	0.246	0.013	0.122
4. Total Cost	0.071	0.010	0.015	0.049	0.266	0.082
5. Retrofit	0.091	0.347	0.517	0.016	0.089	0.212
Total	1	1	1	1	1	1

Table 5E. Normalize Pairwise Comparison

Pugh Matrix - 1									
		Concepts							
Engineering Characteristics		1	2	3	4	5	6	7	8
Mass	Datum	+	+	+	+	+	-	S	+
Energy Consumption		+	+	+	-	+	+	+	+
Flow Rate		-	-	-	+	-	+	-	-
Contaminant Concentration		+	+	+	+	+	+	+	+
Installation cost		+	-	-	+	+	-	+	+
# of pluses		4	3	3	4	4	3	3	4
# of minuses		1	2	2	1	1	2	1	1

Table 6E. Pugh Matrix 1

Pugh Matrix - 2					
		Concepts			
Engineering Characteristics		1	4	5	8
Mass	Datum Concept 2	+	+	+	+
Energy Consumption		+	-	+	+
Flow Rate		-	+	+	+
Contaminant Concentration		+	+	+	+
Installation cost		+	+	-	+
# of pluses		4	4	4	5
# of minuses		1	1	1	0

Table 7E. Pugh Matrix 2

(delete)

The text above the cation always introduces the reference material such as a figure or table. You should never show reference material then present the discussion. You can split the discussion around the reference material, but you should always introduce the reference material in your text first then show the information. If you look at the Figure 1Figure 1 below the caption has a period after the figure number and is left justified whereas the figure itself is centered.

Figure 1. Flush left, normal font settings, sentence case, and ends with a period.

In addition, table captions are placed above the table and have a return after the table number. The second line of the caption provided the description. Note, there is a difference between a return and enter. A return is accomplished with the shortcut key shift + enter. Last, unlike the caption for a figure, a table caption does not end with a period, nor is there a period after the table number.

Table 1

The Word Table and the Table Number are Normal Font and Flush Left. The Caption is Flush Left, Italicized, Uppercase and Lowercase

Level of heading	Format
1	**Centered, Boldface, Uppercase and Lowercase Heading**
2	**Flush Left, Boldface, Uppercase and Lowercase**
3	***Indented, boldface lowercase paragraph heading ending with a period***
4	***Indented, boldface, italicized, lowercase paragraph heading ending with a period.***
5	*Indented, italicized, lowercase paragraph heading ending with a period.*

References

There are no sources in the current document.

Heating, Ventilation and Air-Conditioning Systems, Part of Indoor Air Quality Design Tools for Schools | US EPA, Safety and Health Topics | Indoor Air Quality | Occupational Safety and Health Administration, OSHA 3348 METAL SCRAP RECYCLING