K-12 Classroom Ventilation for Slowed COVID-19 Transmission

Team 9.1

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ABSTRACT

The COVID-19 pandemic continues to impact the lives of many people with over 15 million cases in the last 6 months. Cases are rising and disproportionately affecting low-income communities. A lack of proper ventilation contributes to the spread of the virus in these communities. Poorly funded K-12 schools in the U.S. have shown high transmission rates relative to organizations that can afford adequate ventilation. The existing solution space for ventilation lacks an option that is reliable and cost-effective for classrooms. A solution that fills these gaps could decrease the transmission of COVID-19 in poorly funded K-12 schools.

EXECUTIVE SUMMARY

The team has chosen to address an implication associated with the ongoing COVID-19 pandemic. Specifically, low-income communities experience disproportionate effects of COVID-19, and the team is focusing on trying to help the people in these communities by slowing the transmission of the virus.

Research was conducted on COVID-19 in low-income communities and needs statements were created. A three-part needs selection process was conducted to narrow needs statements from the starting 45 to a final needs statement. Filter one checked for mechanical-based solutions and team interest. Filter two eliminated needs which were not feasible. Filter three involved the use of a Pugh chart to select one of the final six needs based on their scores in seven different categories. These categories were stakeholder impact, availability of resources surrounding the topic, market size, solution landscape, post COVID-19 stakeholder impact and market size, and lastly, team interest. Using this strategy, the team landed on the following need: "There is a need for a low-cost and effective way to ventilate classrooms to deter the transmission of the COVID-19 virus in K-12 schools in the United States"

The WHO sets a standard of 5-6 air changes (which is described as the entire volume of air in the room being replaced) per hour in classroom environments to help slow the transmission of airborne viruses such as COVID-19 [1]. This need is specific to poorly funded K-12 schools who are not able to financially support adequate ventilation. With additional research, the group developed requirements and specifications to satisfy the given need. Eight requirements were developed: the ability to ventilate air, inexpensive, aesthetically pleasing, portable, durable, quiet, usable, and safe. Each requirement was assigned a priority and has accompanying specifications that are justified through research.

After the development of requirements and specifications, concept generation commenced. One-hundred concepts were initially generated using brainstorming, morphological analysis, and design heuristics. The concept selection process involved a feasibility check, a gut check, and preliminary engineering analysis. Ultimately, the team chose a box fan and filter stand-alone unit as the final concept.

From here, the team has developed a functioning prototype. Two tests were carried out with this prototype: one to determine the ability to ventilate air, and one to determine the noise level. Other requirements were analyzed using basic deduction and back-of-the-envelope calculations. Some high and medium priority requirements were not conclusively met during engineering analysis. These include safety, usability, and durability. With more resources and time, these requirements may be addressed. One major critique of the current model is that its performance is heavily dependent on how the user assembles it. The intention was for a DIY solution, but that makes it difficult to perform testing that can generalize to all users in their individual contexts.

PROBLEM DESCRIPTION

COVID-19 Background

A coronavirus is a compact nucleic acid package of RNA associated with proteins or lipids[2]. In December of 2019, a coronavirus known formally as SARS-CoV-2 emerged in China. The COVID-19 virus can be transmitted through the air, and within 9 months of the virus's emergence, over 200,000 fatalities were reported due to COVID-19 [3]. With nearly 15 million reported cases in the last 6 months[4], the pandemic is far from over.

Scientists and researchers have developed and deployed a vaccine for COVID-19. The three common vaccines are produced by Pfizer-BioNTech, Johnson & Johnson, and Moderna. The Pfizer-BioNTech and Moderna vaccines are both 2 dose mRNA vaccines, while the Johnson and Johnson vaccine is a single dose recombinant replication-incompetent adenovirus-vector vaccine [5]. All three vaccines have been given Emergency Use Authorizations (EUA) by the Food and Drug Administration (FDA). Despite the FDA's approval and widespread implementation of the vaccines, COVID-19 cases are still rising.

Communities of all income levels have been impacted by the COVID-19 pandemic. Schools across the world shifted to a virtual learning environment, and many students on college campuses were temporarily placed in quarantine housing after contracting the virus. Hospitals started rejecting visitors to limit the spread of the virus, and nursing homes needed to take major precautions to protect their at-risk residents. Many countries enforced a nationwide lockdown in the early stages of the pandemic. During lockdowns, only essential workers were to report to work, and many small businesses were forced to shut down.

Elderly people are at a higher risk to be seriously affected by COVID-19 compared to younger people. Those who are between ages 70-79 experience a mortality rate of 18.5%, while those below 50 years old experience a mortality rate of less than 1% [6]. Furthermore, buildings that house elderly people must be extra cautious in caring for the residents to avoid transmission of the COVID-19 virus.

One key strategy that has been supported and adopted by many to prevent the spread of the virus is the use of face coverings. Data now exists to support the use of face coverings as a nonpharmacological way to reduce transmission [7]. Many hospitals, businesses, grocery stores, and other common spaces have required the use of face coverings in their efforts to continue service during the pandemic. See the table below that highlights the effectiveness of mask usage to prevent the spread of the virus in various areas.

Table 1: Studies of the Effect of Mask Wearing on SARS-CoV-2 Infection Risk [7].

Source	Location	Population studied	Intervention	Outcome
Hendrix et al	Hair salon in Springfield, Missouri	139 Patrons at a salon with 2 infected and symptomatic stylists	Universal mask wearing in salon (by local ordinance and company policy)	No COVID-19 infections among 67 patrons who were available for follow-up
Payne et al	USS Theodore Roosevelt, Guam	382 US Navy service members	Self-reported mask wearing	Mask wearing reduced risk of infection by 70% (unadjusted odds ratio, 0.30 [95% CI, 0.17-0.52])
Wang Y et al	Households in Beijing, China	124 Households of diagnosed cases comprising 335 people	Self-reported mask wearing by index cases or ≥1 household member prior to index case's diagnosis	Mask wearing reduced risk of secondary infection by 79% (adjusted odds ratio, 0.21 [95% CI, 0.06-0.79])
Doung-ngern et al	Bangkok, Thailand	839 Close contacts of 211 index cases	Self-reported mask wearing by contact at time of high-risk exposure to case	Always having used a mask reduced infection risk by 77% (adjusted odds ratio, 0.23 [95% CI, 0.09-0.60])
Gallaway et al	Arizona	State population	Mandatory mask wearing in public	Temporal association between institution of mask wearing policy and subsequent decline in new diagnoses
Rader et al	US	374 021 Persons who completed web-based surveys	Self-reported mask wearing in grocery stores and in the homes of family or friends	A 10% increase in mask wearing tripled the likelihood of stopping community transmission (adjusted odds ratio, 3.53 [95% CI, 2.03-6.43])
Wang X et al	Boston, Massachusetts	9850 Health care workers (HCWs)	Universal masking of HCWs and patients in the Mass General Brigham health care system	Estimated weekly decline in new diagnoses among HCWs of 3.4% after full implementation of the mask wearing policy

Another way to slow the spread of an airborne virus is through effective ventilation of common spaces [8]. To ventilate a room is to circulate the air so that particles are not stagnant in the ventilated space and fresh air can enter the space. The WHO recommends various hourly air change rates to prevent airborne transmission of pathogens: 0.35 air changes per hour for homes, 2–3 for offices, 5–6 for schools and 6–12 for hospitals [1].

Problem Overview

The COVID-19 pandemic has had a disproportionately large effect on low-income communities [9]. See the Figure below for a visualization of how those in lower-income settings perceive their susceptibility with respect to the COVID-19 pandemic. Among the many possible rationales for this phenomenon are the intricacies of poverty and limited access to healthcare. India is currently being hit by a second wave of cases, affecting millions of people and straining an already-weakened healthcare system. In recent months, India was reported to have some of the highest infection and death rates in the world.

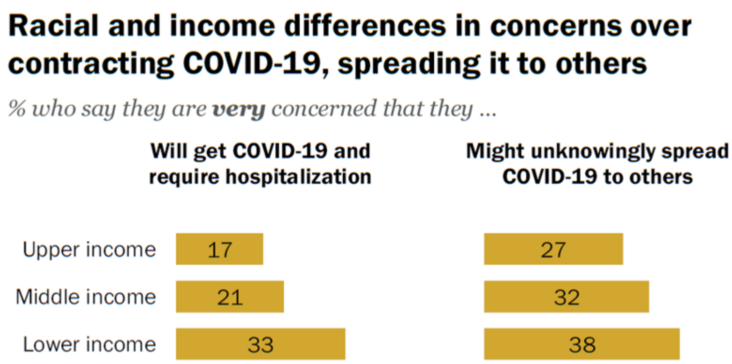


Figure 1: Shown above is a visualization of how different groups of people feel about the effect that COVID-19 has on them. It can be observed that those in lower-income settings feel that they are more likely to contract and spread the virus [10].

The team is strategically focusing on helping low income communities by aiding in the prevention of the transmission of the SARS-CoV-2 virus. Low-income communities have often been observed to have inadequate ventilation systems [11]. Since inadequate ventilation can be associated with higher virus transmission, it can be said that the lack of proper ventilation in low-income communities is contributing to a rise in COVID-19 cases.

NEEDS FINDING METHODS AND RESULTS

General Procedure

Needs finding began with the India COVID SoS list of 39 engineering challenges found in India's pandemic response [12]. These challenges ranged from masks to O2 generation to ventilation and concerns with field hospitals for overflow patients. To expand on these needs, contacts were made at University of Michigan with Dr. Andre Boehman, a professor who has conducted research on virus transmission, and Stephen Brabbs, a regional facilities manager who works on similar projects. Additional research was conducted via web-based scholarly research into topics sourced from India COVID SoS. Specifically, keywords such as "transportation," "power outages," "ventilation," "air quality," "clinical care," and "filtration" were used in conjunction with COVID-19 India and later COVID-19 United States.

NEEDS FILTERING AND RESULTS

Following the needs finding methods, the group was left with 45 needs statements ranging in location, source, and topic. They were faced with the challenge of narrowing this large group down to one final need statement. The team used a three filter process to eventually lead to a final need.

Filter one aimed to eliminate the majority of needs which the group lacked interest in. The two criteria in this filter were team interest as well as mechanical engineering based design process. Team interest aimed to eliminate any needs which lacked any interest from the team after a first glance. Mechanical engineering based design process was defined as needs that clearly required a thorough design and build process to solve. The group put an emphasis on wanting to use what was learned in previous mechanical engineering manufacturing and design classes towards this project. An example of a cut need is “There is a need for a way to recharge Zeolites poisoned by moisture for use in O2 concentrators.” Zeolites are minerals that absorb moisture that require a method to eliminate this moisture to recycle the Zeolites for continued use in O2 concentrators. The group felt this need required a stronger chemistry and biology background in order to solve as opposed to a mechanical solution. Using this filter, the majority of the needs were eliminated leaving the team with just 12 from the original 45.

Filter two focused on the availability of resources surrounding each of the remaining solutions and the feasibility of completing projects. Availability of resources was chosen to eliminate projects requiring high initial capital to begin work. Some needs required high tech machinery that was simply out of the team’s budgets. Feasibility focused mostly on time but could reach out to other characteristics as well. The group wanted to be able to make significant progress on a project rather than having to pass on a half completed project to an incoming team. An example of a need that was cut in this filter was “There is a need for oxygen concentration machines that function at higher altitudes under the reduced barometric pressure in India.” This need was cut for a few reasons. Starting with availability of resources, oxygen concentration machines that would run at the required scale would cost between $1500 and $10,000. A conclusion was reached that this would be out of the given budget for this semester. Regarding feasibility, this project could have potentially been completed in the given time frame; however, in reference to the required low barometric pressure setting it was concluded that testing with this required specification would be difficult to accomplish. Using this filter, the list of needs was cut from 12 to a final six, which are discussed below. A diagram of the filters leading up to the team’s final filter can be seen in Figure 2 below.

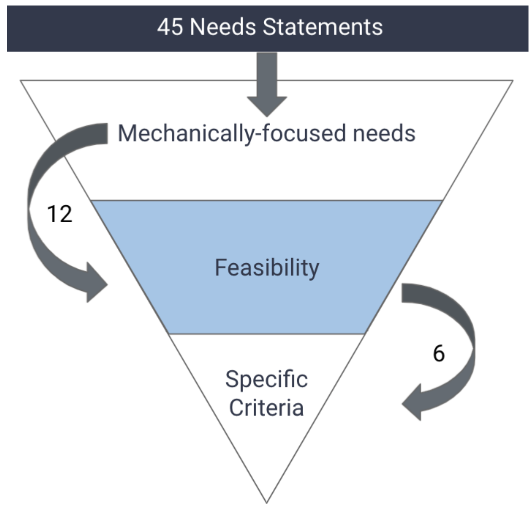


Figure 2: Diagram of Needs Filtering Process

Specific Final Needs
<u>Need 1</u> - There is a need for a low-cost and efficient way to sanitize the air in small rooms that house Covid-19 patients to prevent the spread of the virus.

The above need originated with the "How to ventilate a small room environment?" challenge from India COVID SoS [12]. EPA guidelines on indoor air in homes gave background on strategies to lower transmission rates indoors [13]. There are two main ways to address aerosol transmission of coronavirus: sanitization and ventilation. Sanitization involves physically removing virus particles from the air. Because COVID-19 is transmitted through the air, sanitization significantly lowers the rate of infection. The most effective solution on the market is a High Efficiency Particulate Air (HEPA) mechanical filter. For filters, the recommended effectiveness is the ability to filter out 90% of airborne particles 3 μm to 10 μm in diameter and 50% of airborne particles 0.3 μm to 1 μm. HEPA filters are capable of removing 95% of airborne particles 0.3 μm to 1 μm from the air. Other existing solutions are portable air filters, electronic filters, and UV-C rays. HEPA filters are the gold standard for air filtration [14]. Important stakeholders for air sanitization would be those infected with or at risk of infection from COVID-19, those providing care to patients, the facilities housing them, and HVAC companies installing the systems.

<u>Need 2</u> - There is a need for a low-cost and efficient way to ventilate K-12 classrooms to prevent the transmission of the Covid-19 virus.

Ventilation is a strategy to lower transmission rates of COVID-19 by replacing virus-containing air in a room with clean air from outside, typically measured in air changes per hour. This need was found from the same source as the sanitization need above. Ventilation is distinct from air sanitization though, which justifies making it a separate need. Because COVID-19 is spread through the air, ventilation is an effective strategy to mitigate transmission. Existing solutions to increase ventilation in rooms are window-mounted air conditioning units, opening windows or screened doors, evaporative coolers, and portable fans. There is no one-size-fits-all solution, but a combination of well-positioned fans is very effective for increasing ventilation [13]. The stakeholders are those infected with or at risk of infection from COVID-19, those providing care to patients, and the facilities housing them.

In an interview with the Regional Facilities Manager at the University of Michigan, Stephen Brabbs, it was found that the ventilation systems in well-funded organizations and buildings are adequate and helpful in slowing the spread of COVID-19. However, in poorly funded K-12 schools, the ventilation systems are not up to the same standard. Furthermore, poorly funded K-12 schools are an example of a low-income community that may need a low-cost and effective ventilation system to slow the transmission of COVID-19.

<u>Need 3</u> -There is a need for a low-cost reusable face covering with better filtration characteristics than cloth masks to help slow the spread of Covid-19 in the US.

The above need originated from the need for “effective mask designs for general Indian public” from the India COVID SoS site [12]. Further research was conducted, and it was found that surgical masks are effective in declining the growth rate of COVID-19 [15]. However, since this is a continuous strategy to try and minimize the transmission of the virus, there is room for improvement. Cloth masks are cheaper than medical masks, so they are used more by the general public, but they are not as effective as medical masks [16]. Therefore, there is a need for a face covering that rivals the price of the cloth mask while maintaining the effectiveness of a medical mask. Cloth mask producers, medical mask producers, and the general public are all stakeholders for the new mask design. Both competing mask producers would see drawbacks from the success of a low-cost and effective mask design.

<u>Need 4</u> - There is a need for a way to provide easy access to clean water in hospitals to be used for the care of hospital patients in India.

Clean water serves a variety of purposes for hospitals. It is bottled for the consumption by patients, staff, and visitors. Clean water is also needed for the plumbing system. The supply for bottled drinking water and hospital main water in India has previously been reported to be contaminated by bacteria [17]. As a result, there was an outbreak in infections. There is a need for easier access to clean water in hospitals in India to prevent the spread of infections. Countries that have seen issues relating to a lack of access to water in their hospitals have often resorted to reallocating funds as a solution [18]. Many other existing solutions tend to focus on societal infrastructure rather than mechanical principles. Stakeholders involved in a clean water initiative in Indian hospitals include the patients and staff of the hospitals. The local water distribution organizations also hold stake in this need. Many citizens in India would benefit greatly from reliable access to clean water in hospitals, but the local government may face costs as they reform the infrastructure of water distribution in these areas.

Need 5 - There is a need for an off the grid power source which can power O2 concentrators during power blackouts for COVID-19 patients in India.

In 2012 there was a blackout in India that left 700 million people without power including hospitals for over 12 hours [19]. In the United States they require these hospitals to have a generator to be able to power life-maintaining equipment. The issue with these devices is that they range from $16,000-$85,000 per unit [20]. Lower income areas with large populations such as India can not afford these generators. When these blackouts occur the oxygen systems can go out and can cost patients lives. With over 40,000 health-care facilities in India alone there is plenty of opportunity to improve these systems to account for these power blackouts to help save patients' lives [21].

Need 6 - There is a need for a method to transport COVID-19 patients to health care facilities through busy streets faster and safer in India.

Traffic in densely-populated urban areas of India can prevent emergency services from reaching and transporting critically ill COVID-19 patients to primary care facilities in a timely manner [12]. There are several organizations that keep a count of COVID-19 infections and deaths worldwide, but it is difficult to ascertain the number of hospitalizations in India. Given their almost half a million deaths due to the coronavirus pandemic, it is safe to assume hospitalizations require timely delivery of potentially life-saving care [22]. The current gold standard solution is transport via the Emergency Ambulance Service, which is free in India [23]. Ambulance size can be a limiting factor however in the speed of transport of patients. Other solutions include public transport, which could be dangerous to drivers and other users, and personal transport such as motorcycles, which are unusable for severely ill and unconscious patients. India also has the second cheapest taxi fares in the world, so if proper precautions can be taken for the health of the driver, this is another viable solution [24]. The primary stakeholder is the patient, but other minor stakeholders include families, the ambulance service, and other drivers on the road. With ambulances already at no cost to the consumer and taxis at a low cost, any solution would have to be cheap to the user, be paid for by the government, or both.

Final Need Selection

The final filter referred to specific criteria the team deemed relevant in deciding a final need. For this final filter, seven specific criteria were identified: stakeholder impact, availability of resources, market size, solution landscape, post COVID-19 stakeholder impact and market size, and team interest. Each of these criteria were given their own weight from 1-5 based on their respective importance.

Stakeholder impact was defined as the potential lives that could possibly be impacted by the solution. It was given a 5 in weight because the main priority of global health projects is to protect as many lives as possible. Availability of resources was defined as the availability of resources surrounding each need. This was given middle priority as a 3 on the weight scale because it was important to have access to resources to research to learn more about the needs. Market size talks about the profitability of the needs. This was given a weight of 2 because for the product to be successful, it has to be profitable, however, the team did not want to have profitability outweigh the importance of global health. Solution landscape was defined as the number of existing solutions to the needs. This need was given a 3 because the group wanted to be able create something unique rather than build on an existing product. The next two, post COVID-19 stakeholder impact and post COVID-19 market size are easily defined as the stakeholder impact and market size of the given solution after COVID-19. Post COVID-19 stakeholder impact was given a 4 because the team wants the need to continue to be relevant post COVID-19. Post COVID-19 market size was given a 1 because it is important, but not a priority right now. Finally, team interest was revisited and given a 4 on the weight scale. The group wanted to ensure that there would be continued interest in the need throughout the semester so it was weighed highly. A control need was chosen and the 5 other remaining needs were compared to this control need by issuing a +1 if it accomplished the criteria better than the control need, a -1 if it was worse, or a 0 if they were similar in the selected criteria. A Pugh chart to clearly display all this information and calculate final scores can be seen in Table 2 below.

Table 2: Pugh Chart to Determine Final Need

Criteria	Weight	Need 1	Need 2	Need 3	Need 4	Need 5	Need 6
Stakeholder impact	5	0	0	0	0	-1	-1
Availability of resources surrounding topic	3	0	0	+1	-1	0	-1
Market size	2	0	0	+1	-1	-1	0
Solution Landscape	3	0	+1	-1	+1	0	0
Post-COVID Stakeholder Impact	4	0	0	0	+1	+1	+1
Post-COVID Market Size	1	0	0	-1	-1	0	+1
Team Interest	4	0	+1	-1	-1	+1	+1
Total		0	+7	-3	-3	+1	+1

Using the weighting and scoring scale mentioned before, using Need 1 as a control need, final scores were calculated. Need 2 finished with a significantly higher score compared to the other five needs largely due to the high team interest in this need and also the low solution landscape giving the group a lot of flexibility. This established Need 2 as the group's final need.

SELECTED NEED

The need statement that was selected using the filter process above is “There is a need for a low-cost and effective way to ventilate classrooms to deter the transmission of the COVID-19 virus in K-12 schools in the United States.” Ventilation is described as the circulation of fresh air in a building or room. An example of the difference between good and bad ventilation in a room can be seen below in Figure 3. The WHO sets a standard of 6-12 air changes (which is described as the entire volume of air in the room being replaced) per hour in health-care facilities to help slow the transmission of airborne viruses such as COVID-19. This standard is changed to 0.35 air changes per hour for homes, 2-3 for offices, and 5-6 for schools although these standards are set by WHO they are rarely met at all facilities [1]. It was found that 41 percent of school districts in the US had a need to update or replace their current air systems in a majority of their schools [25]. This is partly due to the high cost of current existing solutions having a wide range of costs $20-$2500. CDC also states that the transmission of SARS-CoV-2 is mostly due to the inhalation of the virus rather than transmission from contaminated surfaces [26]. A study was conducted testing the transmission of COVID-19 due to poor ventilation. In this study it was found that the ventilation in a restaurant was at 0.9 L/s per patron but the standard set by ASHRAE is 8-10 L/s per patron. The study showed that the 10 people who got infected were not in close contact with each other and the outbreak was caused by the poor ventilation in the room [27].

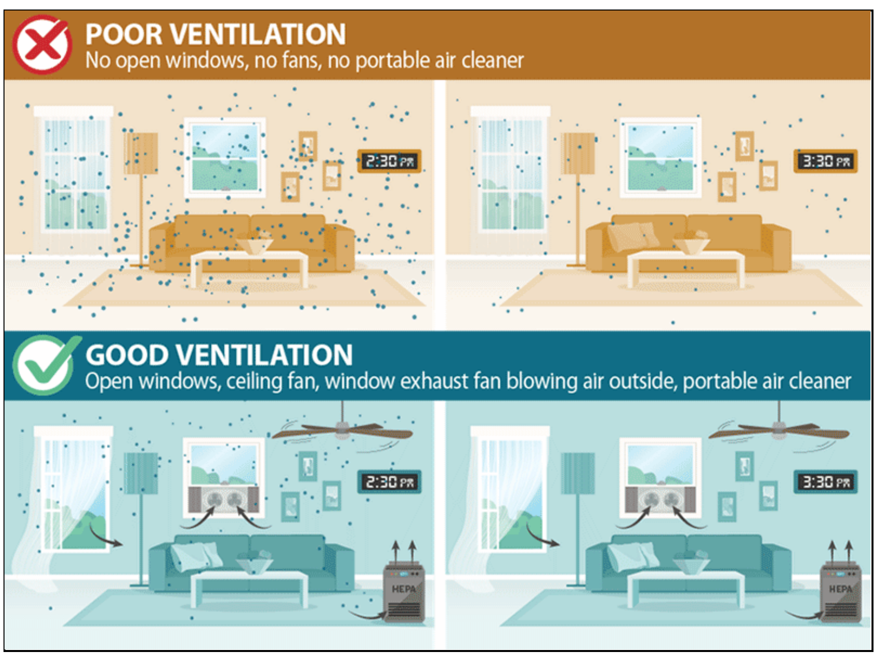


Figure 3: Comparison of a living room with good and bad ventilation [28].

This need is specific to lower income communities since they are the locations that are affected the most by poor ventilation. For class rooms and nursing homes in lower income areas, it is difficult to provide a device for every room that can improve the air ventilation. When looking at the additional needs of high poverty school districts, students receive $2,000 less per student compared to low-poverty school districts [29]. Displaying that higher poverty school districts are already lacking enough resources to provide needs to students making it difficult to have the necessary ventilation requirements and maintenance staff on hand who specialize in this field. Below in Figure 4 the image displays the gap in funding from high to low poverty school districts. The red states represent the gap in funding increasing in favor of the high poverty states, while the green states the funding gap is decreasing. Even with vaccination adoption and students being required to wear masks in public schools outbreaks are still happening here in Michigan. Recently in schools in September there were 71 outbreaks in Michigan that contained 344 cases [30].

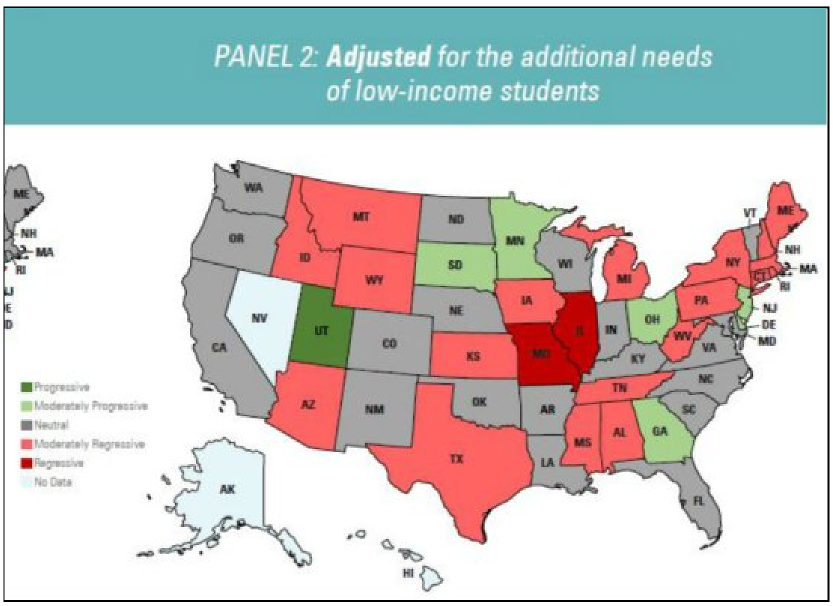
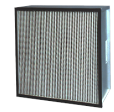
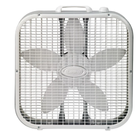


Figure 4: The gap in funding for high and low poverty school districts in the US [29].

Table 3: Existing ventilation solution benchmarking

Solution	Pros	Cons	Cost	Image
HVAC with HEPA Filter	Long service life Excellent air quality	Expensive to install	$80-200 [1]	
Air Purifier	Portable	Space Windows closed	$120-300 [1]	
Box Fan	Portable Directed air flow Cheap	Noise Ventilates only	$20 [2]	
Portable Air Conditioner	Cools air Easy to install	Expensive Loud Inefficient	$400-700 [3]	
UV Fan	Sterilizes air	Very expensive Possible health risk Unproven	$1400+	

In Table 3 above, five different existing solutions are displayed. First, looking at HVAC systems with HEPA filters. These systems are good at providing air quality, they remove 99.97% of airborne particles sized at 0.3 µm [31]. The size of 0.3 µm is specified since it is the most penetrating particle, smaller and larger particles have higher efficiency rating which would be enough to combat COVID-19. EPA states for a ventilation device to be effective in removing a virus from the air they must be able to remove particles as small as 0.1-1 µm, which these HEPA filters can do. The devices themselves also have a long service life but the downside to these devices is that the HEPA filters must be changed every 6-18 months. These can add up to being a very expensive solution with the filters ranging from $80-200 for each filter. Next, for air purifiers they have the advantages of being very portable and able to meet air quality standards for correctly sized rooms. The downsides of using these air purifiers are they can also have filter changes that are costly in their lifespans, as well as for them to work most effectively windows need to be closed. Then, another existing solution is box fans. These solutions are very portable being usually only around 20" x 20" and weighing under 10 pounds. They are also very cheap, ranging around $20-40 for each fan [32]. The downsides to these fans are that they are only really effective when there is already outside air coming into the area. They also can be quite noisy. Portable air conditioners are another current solution for ventilation. The perks of using these devices are that they cool the air in the rooms and typically are easy to instal. A few of the other ventilation systems do not have cooling capabilities, this would cause warmer climates to have to invest funds in additional systems to cool rooms. The downside of using these units is they are expensive ranging over $400 per unit [33]. The finally existing solution is UV fans. They were found to be very effective sanitizing the air, adding up to 24 air changes per hour [34]. Some risks for using these fans are if there is direct exposure to the skin or eyes can cause eye injuries or skin irritation [35]. The technologies of these fans are relatively new when trying to use them for COVID, causing them to become very expensive. These fans usually cost over $1400.

Table 4: Existing solutions compared to solution requirements

	Ventilation	Cost	Portability	Durability	Usability	Noise level	Aesthetically Pleasing
HVAC	✔	✘	✘	✔	✔	✔	✔
Air Purifier	✔	✘	✔	✘	✔	✔	✔
Box Fan	✘	✔	✔	✔	✔	✘	✘
Portable Air Conditioner	✘	✘	✘	✔	✔	✘	✔
UV Ceiling Fan	✔	✘	✘	✔	✘	✔	✔

Table 4 above summarizes the benchmarking of the five existing solutions against seven solution requirements. There is a considerable gap seen in the affordability and portability of existing solutions. Products that do address this concern lack in other aspects such as ventilation, noise, or durability. The lack of a ventilation system that can address the selected need in a cost-efficient way justifies the need's lower-income audience. Specifications for the requirements listed are defined based on this benchmarking in the requirements and specifications section of this report.

REQUIREMENTS AND SPECIFICATIONS

The team has come up with eight requirements and associated specifications that the design must meet in order to adequately address the selected need. That is, the designed ventilation system must meet the following requirements and specifications in order to aid in the prevention of transmission of the COVID-19 virus in low-resource classroom settings.

Table 5: Requirements and Specifications for the Specific Need.

Requirements	Specifications	Priority
Able to ventilate air	1. For 10000 ft^3 room, can ventilate air 6 times per hour.	High
Inexpensive	1. Initial cost to consumer is less than $300 per unit	High
Safe	1. Moving parts are not touchable 2. No sharp edges 3. No exposed electronics	High
Durable	1. Functional for use 12 hours per day, 185 days per year, for 10 years 2. Requires maintenance no more than once per year	Medium
Quiet	1. Produces less than 53 decibels while in operation	Medium
Usable	1. Moving parts are not touchable 2. Does not require the use of an instruction manual to operate	Medium
Aesthetically pleasing	1. Scores at least 3.0 on average on a five-point Likert Scale	Low
Portable	1. Weight < 51 lbs 2. Able to fit through a standard 80" x 36" door frame	Low
Color coded based on level of development of the specifications. Green indicates a highly developed requirement, yellow indicates a moderately developed requirement, and red indicates a low level of development.		

The context of the use setting involves the availability of a standard power outlet (120V) and access to a window in the case that the selected design requires access to outside air.

Requirement 1: The solution is able to ventilate air

This requirement of being able to ventilate air is the basis for this project. The requirement was given a priority of “High” due to how essential this is for the product to be functional to the target audience. COVID-19 transmission in low-income communities, especially schools, are affected the most by poor ventilation. The WHO sets a standard of 5-6 air changes (which is described as the entire volume of air in the room being replaced) per hour for school classrooms to help slow the transmission of airborne viruses such as COVID-19. Although these standards are set by WHO they are rarely met [1]. Based on these standards, a specification was established: for a 10000 ft^3 room, the product can ventilate air 6 times per hour. This would satisfy the standards set by WHO for not only schools, but also homes and office rooms. This requirement was denoted green in table 5 due to the established standards behind it.

Requirement 2: The solution is inexpensive

This requirement for the solution to be inexpensive was derived from the need to make a device for lower income areas. The requirement specification was set to have less than $300 initial cost to the customer. This number was dictated by looking at the current solutions, speaking to stakeholders, and doing research on the feasibility to make a device at this price that meets ventilation requirements. The current devices that are discussed being used to help combat COVID-19 have a large range of prices. The lower priced items such as box fans being around $20 but not being effective units for all types of rooms or situations. Then, the higher priced devices range from $400 up to $2500 for single unit devices, where for some areas they would need more than just one of these devices to have sufficient ventilation. The HVAC team at the University of Michigan discussed the price point of $300 for lower income K-12 schools stating it was a feasible price point and much lower cost then the devices they used at the university. The requirement was given a “High” priority since it is essential to the need to make the device usable in lower income areas. With the use of these resources the solution was denoted a green color to indicate the requirement is very developed and established.

Requirement 3: The solution is aesthetically pleasing

The requirement for the solution to be aesthetically pleasing was derived from a concept of basic human instinct. A device that looks unsafe or unpleasant will likely not be used as much as a device that does look safe and well-developed. This requirement was classified as “Low” priority because it is not essential to the functionality of the product. Furthermore, if the design is not aesthetically pleasing, it may still be able to ventilate air properly. Only the frequency of use is affected by the failure of meeting this requirement.

In order to be necessarily considered “aesthetically pleasing,” the team has come up with a specification involving a Likert Scale score. Moreover, the design must receive an average score of 3 or higher on a five-point Likert Scale amongst a sample of users. The scale to be used can be seen below.

Table 6: Likert Scale used for specification of aesthetic pleasure.

Point	Meaning
1	Strongly Dissatisfied
2	Dissatisfied
3	Neither Dissatisfied nor Satisfied
4	Satisfied
5	Strongly Satisfied

The Likert Scale seen above is the same scale that was used in a study done by the Melbourne Airport in 2016 to assess the satisfaction that its customers experienced in the airport[36]. The team was drawn to the use of this specific scale because there is an option to select neutral. It is expected that many users of the selected design may be indifferent about the appearance of the product, and a neutral option will cater to these users. To determine what score the design must obtain to necessarily meet the requirement, the team consulted with the U-M HVAC Team. It was suggested that any average score higher than 3.0 would suffice in classifying the product as aesthetically pleasing. Since the appearance of the design is not critical to the functionality of the product, the neutral score of 3.0 was agreed upon.

This requirement and specification pairing is denoted green in Table 5 because it is backed by sound research and logic to explain why the design needs to be aesthetically pleasing.

Requirement 4: The solution is portable

The requirement for the solution to be portable was arrived at by considering the use setting for the product. There are often many classrooms in a K-12 school, and it is impractical to purchase a ventilation unit for every room. Therefore, an effective solution will support the transportation from room to room on a regular basis. Furthermore, the design must be portable. This requirement was classified as "Low" priority because it is not essential to the functionality of the product. Furthermore, if the design is not portable, it may still be able to ventilate air properly. However, the appeal to the customer will be affected by a lack of portability, and they may be inclined to find an alternative solution to avoid having stationary ventilation systems.

In order to be necessarily considered "portable," the team has come up with two specifications involving the weight and dimensions of the design. First, the design must weigh less than 51 lbs. This metric is in reference to an OSHA recommendation, which was last updated in 1991, that states that a person should lift no more than 51 lbs. See Table 7 below to see how this specification fits with devices that perform tasks similar to ventilation.

Table 7: Weights of products performing tasks similar to ventilation

Product	Weight Range (lbs)
Window A/C up to 18,000 BTU	39-140 [37]
Portable A/C up to 14,000 BTU	53-77 [37]
Complete Ventilation Unit[1]	153-300 [38]

From Table 7, it can be observed that numerous ventilation and similar products are too heavy to carry safely according to OSHA's recommendation. If the team is able to arrive at a design that is able to meet all other specifications besides weight, then a potential solution may be to add wheels to the design so that it does not need to be lifted to be moved.

The second specification for the design to be portable is to be able to fit through a door frame of size 80" by 36". This is the size of a standard door frame found in most classrooms[39], and the design must be able to fit in those dimensions to be able to be transported into the room.

This requirement and specification pairing is denoted green in Table 5 due to the added research backing up the need for a dimensional specification to be considered portable and speaking with stakeholders.

Requirement 5: The solution is durable

The requirement for the solution to be durable was arrived at by keeping cost-effectiveness in mind. A design that needs to be replaced sooner than competitors or requires more frequent maintenance will cost the user more money than if they purchased the competing product. This requirement was classified as "Medium" priority because it is not essential to the functionality of the product, but it does contribute directly to the "Inexpensive" requirement. Furthermore, if the design is not durable, it may still be able to ventilate air properly. However, the user may be more interested in a product that will last longer or require less maintenance due to its lower long-term cost.

In order to necessarily be considered "durable," the team has come up with a specification involving the lifetime and maintenance frequency of the solution. First, the design must be able to ventilate air for 10 years while being used 12 hours per day and 185 days per year. Every state has a different requirement for the amount of time students must spend receiving instruction in school[40]. The typical work day for K-12 teachers is much longer than the students, and is

[1] A complete ventilation unit provides air filtration, air heating and supply to premises.

inconsistent amongst different subjects and ages of students[41]. To account for this inconsistency, an overestimation of 12 hours was used in the specification. North Carolina is the state with the highest number of days required at 185 days. To address the need in all states of the U.S., this maximum number of days was used in the specification. Also, the Department of Energy recommends that users replace HVAC systems after 10 years of use[43]. The second specification for the solution to be considered "durable," is the requirement of maintenance no more than once per year. HVAC systems are recommended to be inspected annually, and maintenance should be expected [44]. Therefore, the design that the team constructs should require maintenance no more frequent than annually.

This requirement and specification pairing is denoted yellow in Table 5 due to the estimation that was required in defining the amount that a potential design would be used daily.

Requirement 6: The solution is quiet

The requirement for the solution to be quiet was arrived at by considering the use setting for the product. In a classroom setting, loud noises will likely disrupt learning by distracting people or prevent hearing. The importance of the noise level of the solution was further emphasized by the U-M HVAC Committee. The committee vocalized that in their experience, if a product is not sufficiently quiet, the user will simply shut off the device. Because of this, the requirement for the device to be quiet was given a medium priority. The reason this requirement was not given a high priority is because the noise level of the device does not affect the ability of the product to function properly. It is simply something that is nice to have. In order to develop a specification for the requirement, the team investigated the use setting of the device. It was found that the average noise level in classroom settings ranged between 53 and 76 decibels [44]. From this, the team set the specification for the requirement to be at 53 decibels as that is the lower end of the noise range. That way, the device will not pose a significant impact on the noise level in the classroom.

This requirement and specification is denoted a green color in Table 5 since it is developed by looking at current classroom and existing solutions volume levels.

Requirement 7: The solution is usable

The requirement for the solution to be usable was arrived at by considering the use setting of the solution. Usable, in the context of this problem, means that the product is safe and easy to use. A usable design is critical in a classroom setting because children may be present and users of the product will likely not have any relevant background in the operation of HVAC systems. The usable requirement was given "Medium" priority because it is not essential for the functionality of the solution, but every user and bystander is affected by the safety or ease of use of the solution.

In order to necessarily be considered "usable," the team has come up with specifications involving the safety and ease of operation. First, the design must not allow physical access to any moving parts. This specification was included to protect the children that may be in the classroom. A curious young student may want to play with the ventilation system, and it is important that there is no way that a moving part will harm the student. Second, the design must not require the use of an instruction manual to operate. This specification was included in consideration of the users, who will likely be busy teachers that have little to no background in the operation of HVAC systems. The exclusion of an instruction manual to be used will save the user time, but also requires some sort of way to convey the operational instructions directly on the design.

The usability requirement is color coded yellow in Table 5 because the team needs to conduct more research into safety and ease of use to add specifications or refine existing specifications. Ongoing research will include usability of existing benchmarked solutions and applicable standards.

Requirement 8: The solution is safe

The requirement for the solution to be safe was arrived at by considering the setting of the solution. The solution is intended to be placed in K-12 classrooms. The team decided to add this requirement in case anyone in the classroom is in close proximity to the product. The specifications were set to be: moving parts are not easily accessible, no sharp edges, and no exposed electronics. These specifications were set by speaking with stakeholders such as the HVAC team and teachers. All of these specifications are expressed by when the device is functioning or turned off the team do not want any students trying to play with the device and getting harmed. Hearing from stakeholders, they discussed that the most common ways for these accidents involving safety are from moving parts such as fan blades, clothing or skin getting snagged on sharp edges, and exposed wires. This solution was given "High" priority since if the product is not safe it will not be able to be used. Also, if the safety isn't a priority even if the device meets ventilation requirements then other issues arise from other concerns besides COVID-19. This requirement is color coded yellow in Table 5 because the team needs to conduct a little more research and testing to see what other concerns that could arise. Since there could be other safety concerns for the device that the team has not considered and should add.

CONCEPT GENERATION

Following the group's solidification of their requirements and specifications, concept generation began. Three separate methods for concept generation were selected based on relevance to the project and also personal preference.

The first method used was brainstorming. This was conducted on 10/22. An hour was spent rapid firing any ideas that came to mind in a very non-systematic matter. One member of the team was assigned the role as scribe and in this role they were tasked with writing down all the ideas that were talked about and also drawing sketches for the ones that could be sketched. The group had some guidelines that they established from their learning of the concept exploration block. The group tried to be upbeat, defer any judgement and to stay focused on the task at hand. In addition, they tried to not talk over one another and to be as visual as possible for the scribe to easily be able to sketch and understand the idea. Overall, the group was able to establish 40 ideas. The full list can be seen in Appendix E with a small screenshot seen in Figure 5 below. There were a wide variety of ideas, including some very unfeasible, but in the end a strong starting point was established. Some of the proposed ideas included installing a UV light system inside the existing HVAC system. This would eliminate a majority of harmful particles that preside in the air resulting in what was classified as an air change. Another potential idea was a vacuum system with two one way valves. One would suck air in from inside and push it outside, and the other would pull air in from the outside and bring it inside. Both would go through some potential filter to clean the air coming in. An idea more out of the box was a mythical creature that would be able to breathe in all the air in the room and then run outside and breathe it all out. It would then take a big breath outside and bring in the new air to the classroom. These crazier ideas helped the group jump into more feasible ones.

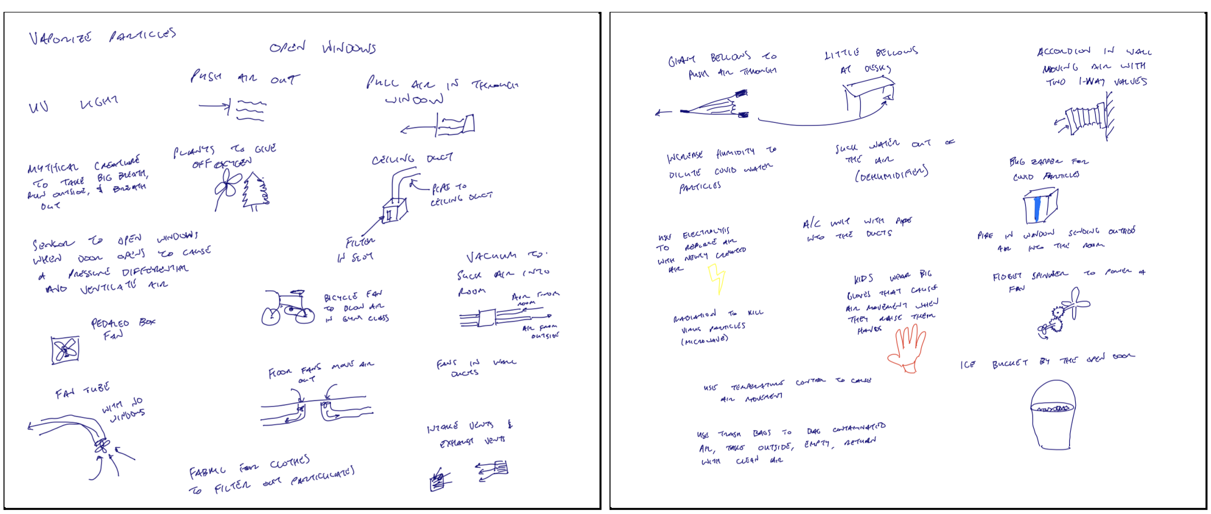


Figure 5: Condensed Brainstorming Sheet

The second method which was used was morphological analysis. This was conducted on 11/3. The morphological analysis was chosen due to it being very different from the brainstorming method. While the brainstorming was very unstructured, morphological analysis is significantly more systematic. Morphological analysis also allows the group to mix and match ideas and will also help with the organization of generated ideas. Similar to the group's brainstorming approach, a scribe was designated to keep track of ideas that were announced. The group began by filtering down the need into ten possible subsystems. These subsystems may be pulled from existing solutions already, but the main goal is for them to be concrete and specific so that the solutions that the group comes up with also are. These subsystems focused on a wide variety of functions that the group felt were crucial to the final product. Some subsystems included were "move air" and "clean air" as well as "power conversion" and "aesthetics". At this point a large table was made and development of possible solutions to the subsystems began. The goal was to generate at least three solutions for each subsystem with many of them having more than the designated three. A picture was drawn to describe the solution in stronger detail and allow for a more visual approach to generation. The completed chart can be found in Appendix E with a screenshot seen in Figure 6 below. From here the group can pick solutions from subsystems and assemble a wide range of solutions to the selected need. At this point, the group had a very large solution space.

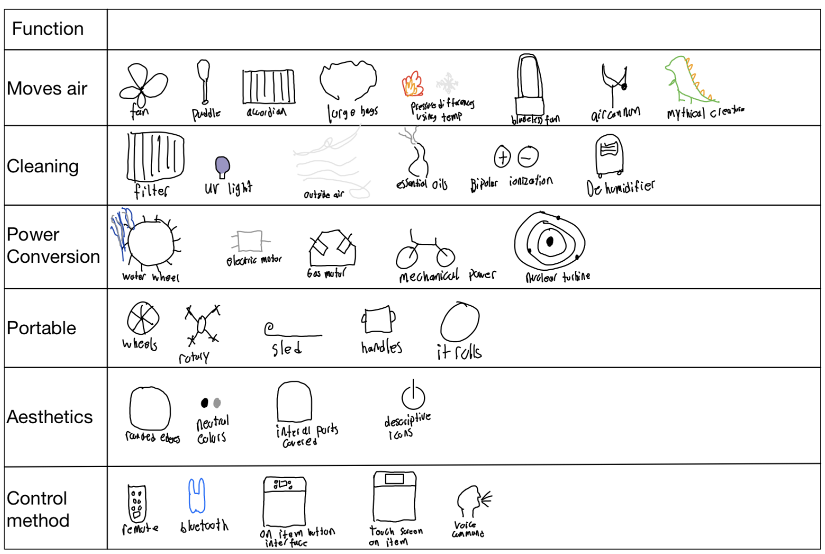


Figure 6: Morphological Analysis Table

The final method which was used was design heuristics. This method was also conducted on 11/3. At this point the group was running low on new ideas and found that ideas were becoming repetitive. Design heuristics allowed the group to explore a variety of concepts they hadn't looked at already and also build on previous ideas. A scribe was designated. The group wanted to make sure the cards were chosen at random to reach outside of the concepts they had already looked at. To do this they utilized a random number generator. The number of cards in the deck, 72, were inserted into the random number generator and ten numbers were generated which would correspond to a matching card. These were the ten heuristics the group would further evaluate. Some of these included “allow users to assemble” and “use continuous material”. Similar to morphological analysis, at least three possible solutions were created for each heuristic but in most cases more were generated. The entire list can be seen in Appendix E and a screenshot can be seen in Figure 7 below. From the list, heuristics can be selected and added onto already existing solutions or entirely new solutions could be created.

Design Heuristics Concept Generation Method
10 Heuristics, 39 Concepts

8.Allow user to assemble: (5)
- Legos
- Interference fits
- Child locks
- Included allen wrench assembly
- Lincoln logs

69. Use continuous material: (3)
- Injection molding
- Vacuum formed
- 3D printed

46. Mimic natural mechanisms: (4)
- Wind
- Pressure differentials
- Plants
- Algae

63: Substitute way of achieving function: (3)
- Bipolar ionization of COVID particles
- UV-C cleaning of the air
- Aerosol spray to clean air

9: Allow user to customize: (5)
- Different ventilation speeds
- Different color on user interface
- Level of filter used
- Colors of device
- Bedazzled

Figure 7: Design Heuristics Condensed List

After going through all three methods the group had generated around 100 ideas. At this point, they felt that ideas were beginning to get repetitive and also wanted to leave time to prototype and go through the testing process. So with that concept generation was finished and concept selection began.

CONCEPT SELECTION

After using the three concept generation techniques explained above, the group had to narrow down the concepts. The first filter that was used tested if the concept was feasible. The feasibility filter was treated as a go/no go test. Looking at the concepts each idea would be evaluated based on current technology capabilities, cost, and safety. Going through this filter, the concepts went from 72 down to 53 concepts. Below in Figure 8 it can be seen some examples of concepts making it through the filter, as well as some that did not.

Masks with UV Light	Fail
Fan with chemical disinfectant	Pass
Bladeless turbine	Pass

Figure 8: Example of concepts being passed through the first filter.

The second filter that the concepts went through was a gut check. This filter was explained in the block discussed: it would list all constraints to each concept, adjust concepts according to listed constraints, and then eliminate concepts that are not able to be adapted to eliminate barriers. The way the team eliminated concepts was based on a supermajority vote. Concepts with less than ⅘ votes in favor of elimination will be subject to a pros and cons discussion before a subsequent vote in which majority would suffice. After going through this second filter only six concepts remained.

Table 8: Final Six Concepts

Concept	How To Fail:	Engineering Analysis Method
Clean air using UV lights on fans	Check safety and cost	Consulting stakeholders & Cost Analysis
Exchange air through windows with fan	Check energy effect during cold months	BOEC of energy loss through windows
Fan and filter put into room as standalone unit	Check cost and number of air changes	BOEC and low-fidelity prototype
Fan with bipolar ionization to sanitize air	Check safety and cost	Consulting stakeholders & EPA
Accordion in existing window moving air using one-way valves	Check usability and energy cost	BOEC of energy loss through windows

Attach accordion device to filter to filter air	Check usability	In progress

Table 8 above shows the final 6 concepts and how they failed. The final filter for these final 6 concepts went through was a final considerations and engineering analysis filter. These concepts were looked into on safety students given the teams background knowledge, as well as doing a back of envelope calculation involving energy use to eliminate concepts. The final 6 concepts are listed in greater detail below.

Clean air using UV lights on fans

The first concept is clean air using UV lights on fans. This concept made it through the first two filters since the concept has been done and used in other locations. The HVAC team said they have used similar fans in the past. The cost of these fans on the market today, over $1,200, is too costly and fails this concept. The University HVAC also mentioned it would be very difficult for the team to create a safe unit using UV-C. The FDA states how direct exposure of skin and eyes to UVC can cause injuries and burn-like reactions, making it difficult for the team to create this unit and resulting in its removal from consideration [45].

Exchange air through windows using fans

The second concept used a fan that exchanges air through an open window. This concept made it through the earlier filters since it was able to ventilate air effectively while keeping it relatively low cost for the unit itself. A back of the envelope calculation was used to conduct engineering analysis on the energy cost of blowing air into a room during colder months in northern states. The analysis found that the energy cost to attain the desired airflow would be $488 per month (Appendix H). Due to the high energy cost, this concept was removed from consideration.

Fan and filter put into room as standalone unit

The third concept was using a fan and filter as a standalone unit. The advantages of this concept that made it get through the first two filters are that it is relatively inexpensive with each filter costing around $10 and a box fan costing $20. Also, these units can be used without open windows. Some disadvantages of this unit are the number of air changes would have to be checked since the team is unsure if this unit can meet specifications. Another disadvantage of this concept is the cost can vary based on the filters being used as well as the amount of them that are needed. Taking these into considerations the team decided to move forward with trying to create a prototype that can be tested and optimized.

Fan with bipolar ionization to sanitize air.

The fourth concept was using a fan that had bipolar ionization to sanitize air. The University HVAC team suggested the concept and stated they had conducted studies showing that it can be effective in sanitizing the air and removing COVID-19 particles. EPA reports these devices can be effective at eliminating the virus [46]. The downside of using this method is they can possibly emit high levels of ozone. Also, there is very limited data on these devices [47]. Looking at these disadvantages and the background knowledge the group had, the team decided to remove this concept.

Attach accordion device to filter to filter air

This concept uses an accordion structure analogous to a bellows to pass air through a filter at one end. It can be mounted either on a wall or on the floor inside a room. Figure 9 below illustrates the design of this concept and how one-way valves can move air into and out of the device. The accordion device concept is completely different from any of the benchmarking solutions. A major disadvantage of the concept is that its novelty makes it difficult to determine the ventilation capabilities or cost. It passed the previous two filters though because the team believed it showed enough promises to remain in consideration. An engineering analysis plan for this concept had not yet been developed when the team decided to transition to a DIY solution.

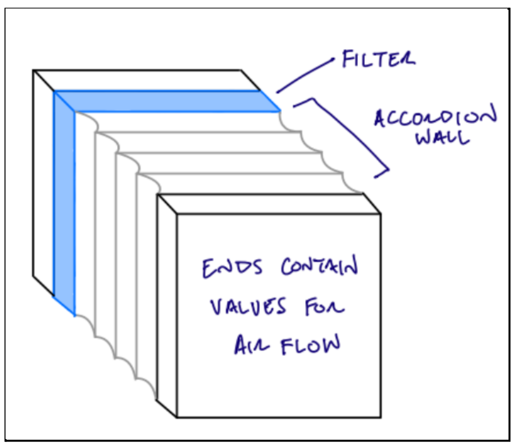


Figure 9: Final Concept 5 using an accordion structure and filter.

Accordion in existing window moving air using one-way valves

This concept is similar to the previous one but it moves exterior air into the room through a window instead of passing it through a filter. The accordion device concept passed previous filters because the novelty of the device made it difficult to determine its cost or ventilation capabilities. However, engineering analysis was used to determine the energy cost of ventilation with outside air. The same back of the envelope calculation that failed the window fan concept due to high energy costs resulted in the elimination of this concept.

FINAL CONCEPT

The team has chosen to pursue the concept involving a box fan and paper air filter combination as a stand-alone unit. The idea to use a box fan to push air through a filter emerged during the concept generation phase. However, the idea to bring the components together as they are in the current version emerged after a meeting with the main stakeholder. During this meeting, the U-M HVAC team presented an existing example of a Do-It-Yourself solution to improve ventilation in a living room [48]. The example solution involves a box fan fastened on top of four air filters, as shown below. Air is sucked in from the top of the fan and is pushed out through the filters.

Figure 10: A DIY solution to improve ventilation, shared by U-M HVAC Team

The team was able to visualize the idea of a box fan-filter combination after discovering the example above, and the following sketch was created. Notice that, similar to the DIY solution, the air is pulled in from above the box fan, and pushed through air filters that are directly below the fan.

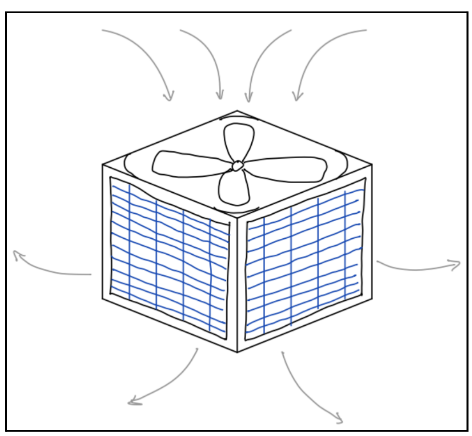


Figure 11: The most recent sketch of the final concept.

There are several key characteristics to highlight regarding the concept. First, this concept was developed under the assumption that the box fan will require access to a standard, 120 V power outlet. Also, since the air is flowing through a filter, there is no requirement for access to new and/or fresh air from outside the classroom.

Given these characteristics, there are several aspects of the final concept that show flexibility and will need to be developed during the remainder of the design process. Because window access is not required, there is also no requirement on where the product should be placed within the classroom. The team has theorized that placing the product in the center of the room may result in more air changes per hour, but this will require further engineering analysis to validate. Also, the geometry of the design is not yet concrete. More specifically, it is not certain if the best results will be obtained when all four walls are filters, or if one or more walls can be replaced by a cheaper alternative like cardboard. Also, the team may find through testing that having the box fan as one of the side walls may allow for the most air changes per hour. The team is keeping the solution space open, and also considering geometries that do not have discrete walls. Some examples that may fall under this category could be a bag-like feature or a net below the box fan.

The team has conducted a brief analysis to gauge their confidence in the final concept's ability to meet each requirement and specification. In the table below, each requirement and specification is listed with an extra column to explain how the designated confidence was assigned. If a row is highlighted green, then the team is very confident that the concept will be able to meet the associated specification(s). If a row is highlighted yellow, then the team is somewhat confident that the concept will be able to meet the associated specification(s). If a row is highlighted red, then the team is not confident that the concept will be able to meet the associated specification(s). Note that this indicated the teams work up until the final concept stage. This does not reflect the results of the testing conducted later in the design process.

Table 9: Final Concept Ability to Meet Requirements and Specifications

Requirements	Specifications	How/Why?
Able to ventilate air	1. For 10000 ft^3 room, can ventilate air 6 times per hour.	Check specs of box fan. Further analysis required.
Inexpensive	1. Initial cost to consumer is less than $300 per unit	Paper filter ⇒ ~$12.5 each (x4) Box fan ⇒ ~$25 each **Initial cost ⇒ ~$75 per unit**
Aesthetically pleasing	1. Scores at least 3.0 on average on a five-point Likert Scale	Stakeholder verification Survey required
Portable	1. Weight < 51 lbs 2. Able to fit through a standard 80" x 36" door frame	Box fan ~7 lbs, each filter < 1 lb Can be assembled in room
Durable	1. Functional for use 12 hours	Box fan has average life span of 12

	per day, 185 days per year, for 10 years 2. Requires maintenance no more than once per year	years May need to replace filters twice per year
Quiet	1. Produces less than 53 decibels while in operation	Average box fan noise rating between 55-65 dB
Usable	1. Does not require the use of an instruction manual to operate	Simple dial on box fan
Safe	1. Moving parts are not touchable 2. No sharp edges 3. No exposed electronics	Box fan has cage for protection

Specific figures in the table above, such as the average cost and weight of a box fan, were arrived at by checking the standards in the current market for box fans and filters. Many of these figures were validated after comparing to the specs of the prototype material that the team has purchased, which is highlighted later on.

The team has explored various ways that the concept can be applied in the use setting. There is the obvious method, where a prototype reaches its final stages of development and is able to be produced on a larger scale and sold commercially. There is another, less obvious method that the team has chosen to pursue. In order to better allocate their resources, it may be beneficial for K-12 schools to have access to an assembly guide for a ventilation system. For instance, the team could expect the final product of the project to be a DIY instruction manual for different variations of the final design. With this, K-12 faculty can make cost-driven or quality-driven decisions that will determine the application of their ventilation system. Ideally, there will be metrics obtained through prototype testing that highlight the effects of these decisions.

ENGINEERING ANALYSIS

With the final concept being a box fan and filter apparatus intended to be delivered via DIY instruction manual, multiple methods were used to optimize various aspects of the concept. Some specifications did not require extensive quantitative analysis, such as the total cost and portability of the concept. The total cost of the latest prototype was less than $75, and the total weight was significantly less than the 51 lb specification. Some specifications were not easily testable given the team's prototypes. These included the aesthetic rating, safety, and usability. In order to identify if the concept meets these specifications, there would be a need for more stakeholder outreach, which the team was not able to conduct in the allotted time. The team had the resources to test the durability requirement, but the time frame of the specification spans much longer than the semester that the project took course over. Lastly, the team was able to conduct engineering analysis on two requirements: Able to ventilate air and quiet.

Two low-fidelity tests were carried out. An air flow test was conducted to determine if the concept is able to ventilate air 6 times per hour in a 10,000 ft^3 room. A noise test was conducted to determine if the concept produces more than 53 dB while in operation. Before going into detail about the conducted testing, an image of the final prototype used for testing is shown below.

Figure 12: The most recent prototype of the design.

The airflow test involved the use of a BTMETER BT-100 Handheld Anemometer to measure the air speed out of the filters. The volumetric flow rate was calculated from the one-dimensional air speed by multiplying the speed by the surface area of all four filters. Several assumptions were made during this process. First, it was assumed that at any instant, the air speed measured at one point would be identical over the entire exposed surface area. Also, it was assumed that all air flowing through the filters was filtered adequately. Because the test was low-fidelity, the team was not hesitant to make assumptions; however, in order for the test results to be generalized to the use setting on a broader scale, a more rigorous test would be required. More information on data processing and final results can be found in the Verification and Validation section.

The noise test involved the use of the Decibel X iOS application on one of the team member's iPhone. The test involved measuring the volume of noise produced by the design from 1 meter away. One assumption was made during this test, which is that students and teachers in the classroom would not be sitting closer than 1 meter to the design. The basis of this assumption is that there would need to be space to walk around the design, so desks and chairs would not be placed that close. More information on data processing and final results can be found in the Verification and Validation section.

Additionally, there was preliminary engineering analysis involved in the concept selection process. Some back-of-the-envelope calculations were done to show that any concept that involves the use of outside air would be too costly. Because the concept may be used during winter months in northern regions, the electricity used to heat the new air would accumulate too much on the electricity bill. The work for this can be seen in Appendix H.

FINAL DESIGN

Design Description

The team's final design ended up nearly the same as their final concept. Some adjustments were made in order to improve the functionality of the design, however, the overall design remained constant. Below, figure 13 displays the bill of materials required in order to create the prototype the team developed and used in testing.

Item Name	Item description	Quantity	Unit Cost	Total Cost
MERV 13 Filter	20 in x 20 in filter fulfilling MERV 13 filtration requirements	4	9.97	$39.88
Box Fan	20 x 20 in Box fan with variable speed adjustment knob	1	19.98	$19.98
Duct Tape	Standard 3" duct tape	1	3.99	$3.99
Extension Cord	20 ft cxtension cord	1	10.99	$10.99

Figure 13: Bill of Materials for final design and prototype

The short list of materials used by the team listed above was a deliberate decision to keep the design as simple as possible. In developing the final design, the team thought of items which were not yet decided at the final concept stage. Some ideas were discussed such as developing a cage which would house the filters. After some deliberation, this idea as well as others requiring non-DIY items were scrapped as they would prevent this design from being completed without the customer purchasing a new product. This difficulty could be circumnavigated in the future by designing a structure which can be 3D printed which most communities have access to in some form. For the purposes of this project, however, the final design opted for the use of duct tape to hold the structure together. While slightly less robust than a specifically designed enclosure, the duct tape allows the user much needed design flexibility. If they desire a filter which is slightly thicker, or want to combine two devices together, this would be impossible with a limiting cage design; however, the use of duct tape allows this flexibility. A detailed sketch of the design can be found below in figure 14 and a picture of the final prototype can be found above in figure 12.

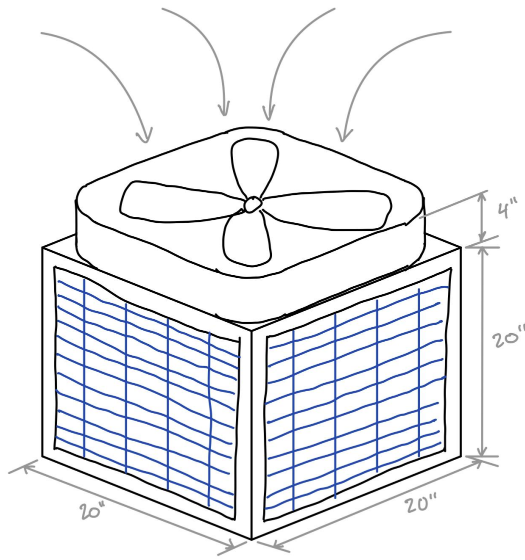


Figure 14: Dimensionalized sketch of final design

When developing the final prototype, the team considered developing both a CAD model as well as a functional prototype. Given time constraints, the team opted to complete only the functional prototype. In the future, a CAD model can be produced which would be useful in simulation testing; however, given that the team would not have time for simulation testing this semester, the team opted to put time towards developing and testing the functional prototype.

Design Functionality

The basic functionality of the prototype relies on the movement of air through the four filters surrounding the box fan. Air is sucked in through the top of the device and pushed into the cavity encompassed by the four filters. The motion of air is displayed by the arrows in figure 14. Then, the pressure difference between the inside of the enclosure and the surrounding air pushes air through the filters and into the surrounding room. This results in clean, filtered air. In order to maximize functionality of the prototype, duct tape was used to close any gaps in the enclosure. This worked to increase the pressure difference between the inside and outside of the enclosure which resulted in higher airflow, meaning more filtration.

Manufacturing Process

All items used in the build of the team's design were selected because they are readily available to consumers. Developing proprietary components would defeat the purpose of the project. As a result of this, the manufacturing process is more of an assembly process. There are essentially two sections of the design: filter section and fan section. The filter section is made by taping together four filters in a cubic formation. The top and bottom sections of the section should remain open. An image of this assembly can be found below in figure 15.

Figure 15: Filters tapes in cubic shape ready to be attached to the box fan.

Next, the box fan is to be placed on top of the four filter enclosure. The fan is then taped to the four filters. Extra tape is used in order to cover any areas where air may leak out of the enclosure. This will improve the functionality of the prototype. An example of this can be seen below in figure 16.

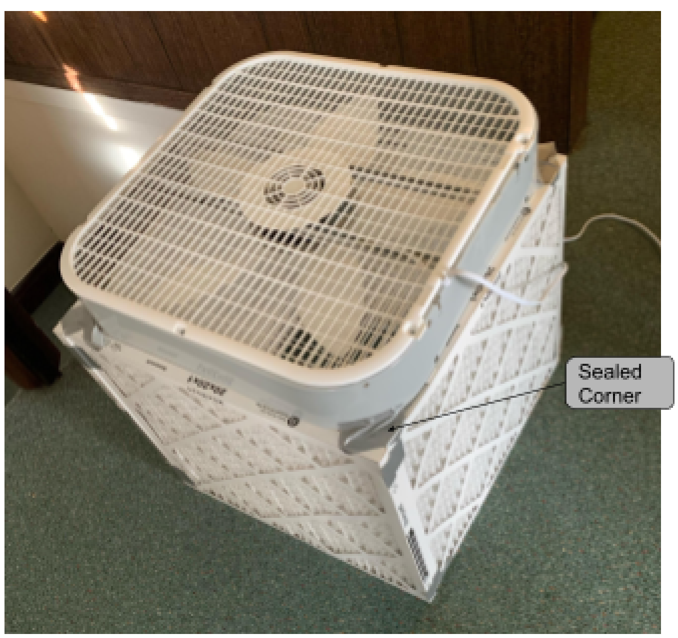


Figure 16: Sealed corner of filter and fan connection

Once this is complete, the design is placed with the open side on the ground to act as a sixth side of the cube. This should result with the fan on top of the device as shown in figure 16. The device is now ready for use/testing.

Contextual Factors

As the goal of this project was to deter the transmission of COVID-19, the virus at the center of a disastrous pandemic, the final design is very closely tied into public health, safety, and welfare. The goal of the design is to decrease the spread among schoolchildren, which will decrease the spread of the virus to their families and others in the community.

In a global marketplace, the design could be adapted to a variety of other settings. The simplicity of design and affordable price point makes it attractive for use in places such as nursing homes, college dormitories, and lower and middle income countries, so long as effective fans and filters are still available for purchase there.

The use phase of the product should have a significant positive social impact by increasing ventilation and decreasing the transmission rates of COVID-19 and other airborne pathogens. The noise level of the final design could negatively affect the classroom setting during use, despite passing the noise level specification. The filters must be replaced every 3-6 months, which could cause negative social impacts in the disposal phase. Frequent disposal of filters could cause a large amount of waste, especially because they are not recyclable. Using longer-lasting filters could help mitigate this problem.

The DIY aspect of the final design may make it very attractive to the consumer on a cost basis. One of the requirements was to have an inexpensive solution. The low cost of the materials and use of filters instead of ventilating with outside air lower the economic impact of the design in both the manufacturing and use phase. All parts of the design would be disposed of at a landfill, which lowers the disposal costs but is not very environmentally conscious.

In order to assess the social impacts of the final design, the ecosystem map included in the discussion section below was used. Primary, secondary, and tertiary stakeholders were all considered but mainly the social impact of the design can be boiled down to its effect on the schools buying the product, the teachers and students using it, and the family members and community interacting with the users outside of the classroom.

VERIFICATION AND VALIDATION APPROACHES

The team used several different testing methods to see if the concept would meet the requirements. Table 10 below shows all the requirements and if the team was able to pass the requirement. The green check marks represent the requirement was met through verification and validation. The blank squares represent the requirement is still in progress. The red X represents that the requirement was not met.

Table 10: Verification and Validation Status for each Requirement

	Status
Able to ventilate air	✔
Quiet	✔
Inexpensive	✔
Portable	✔
Safe	☐
Usable	☐
Aesthetically Pleasing	☐
Durable	✘

To verify the final design prototype met the requirement of being able to ventilate air the team used an anemometer to test the air flow speed through the filters. The device was turned on to the lowest fan setting. Then, the anemometer was placed on the filters at different locations to get the air flow speed in meters per second. Once the air flow speed was found for the filter it was then converted to volume flow rate. Below in Table 11, the volume flow rate can be seen for each trial.

Table 11: Air Flow Testing Results

Trial	Air Speed through Filter [m/s]	Volume Flow Rate [ft^3/hr] (Air Speed x A_T)
1	0.5	65,601
2	0.4	52,480
3	0.6	78,721
4	0.4	52,480
5	0.5	65,601
6	0.6	78,721

Above in Table 11, the A_T was found by doing 4 times the area of each filter to get a total area of 1.032 m^2. The average volume flow rate was then found to be 66,000 ± 500 ft^3/hr. There were several assumptions the team made when calculating the volume flow rate. First, the team assumed the air speed at one point would be the same across the entire surface area. Next, the team assumed the air was filtered adequately throughout the entire MERV 13 filters. This testing method did meet the requirement of being able to ventilate air of 60,000 ft^3/hr. Two ways to try and improve the confidence of this requirement are to try tests with air flow hood in a room or use different anemometers to help validate the tests the team ran. Also, using some more analytical testing, such as being able to use models or simulations to try to confirm the team's test, would have helped triangulate the results. With the resources and time the team had, this method of testing the air through the filter was most appropriate to give the most confidence in meeting the requirement.

The next requirement the team tested for was the noise requirement. The fan was first turned on to the lowest setting for the device. Then, the noise requirement test was conducted by placing a microphone one meter away from the prototype and reading the decibiles the device outputs. The microphone that was used was a team member's iPhone with the app Decibel X iOS. Below in Table 12 the data found for the noise test are displayed.

Table 12: Noise Level Testing Results

Trial	Noise Level (dB) (Measured 1m away)
1	52.5
2	51
3	50
4	51
5	50.5
6	52

The average noise level of the prototype was found to be 51 ± 0.5 dB. There were a few different assumptions made when measuring the noise level. First, that the user would be at least a meter away from the device when it was in use. Next, the device would be uncovered in the classroom. Some ways this testing method could have been further verified is by attempting to test the noise level of the device in different rooms. Another method would be using multiple different microphones to cross references these tests to confirm the noise level. The team test did meet the requirement that was set at 53 dB for the device. Some other tests that could have been helpful to confirm the team's confidence is some user testing. Where users of the product such as teachers and students could confirm the device would not be distracting in a classroom setting.

The other requirement that was passed was being inexpensive. The team bought all the products needed to assemble at a local Home Depot. With the necessary components needed, the prototype ending cost was $75. This met the requirement of $300. Some ways to confirm this could meet this requirement in all locations would be to look at the cost of these components in different areas in the U.S.

The final requirement that the team was able to pass was the device being portable. This test was done by some standard measuring and weighing of the prototype. The device dimensions were measured to be 24” x 20” x 20” with a weight of all the components adding about to be around 8 pounds. This testing method as well as using some inspection testing method by the team it was deduced that the device would be portable to transfer from classroom to classroom. Giving the team high confidence that this requirement is met. The requirement specifications stated the device needed to be less than 51 lbs and fit in a standard door frame with dimensions of 80” x 36”.

Some of the requirements were also unable to be verified due to time or resource constraints. The first requirement which was unable to be verified was the safe requirement. If the team had more time, they would have presented the prototypes to stakeholders, such as teachers, to conduct some inspection testing by them. Another testing method that would have been conducted would be FMEA (Failure Modes and Effects Analysis). This testing method is targeted to find weaknesses in the product when in the hands of the user. The FMEA would be able to locate safety errors that could arise when the device is near children. The team set safety specifications such as no sharp edges, no exposed electronics, and no touchable movable parts, but without user testing in place the team did not confirm that this requirement was fully met.

The second requirement that is in progress is the usability requirement. The device is easily operated, needing only to turn a simple dial to use. Also, the system can be assembled without any tools or prior experience, but without proper user testing, the team did not believe this requirement was fully met. With more time, the team would have conducted user testing in a controlled environment and in a classroom setting to address the usability requirement.

The last requirement that is still in progress is the aesthetically pleasing requirement. This requirement would have involved a likert scale survey passed out to multiple stakeholders, to see if the requirement would meet the 3 on the likert scale. With speaking to the HVAC team as well as some other users, the team believed the device would eventually pass this requirement. But without the time to conduct the survey to be statistically significant, the team cannot say this requirement is passed.

The only requirement that was not passed was the durable requirement. One major component to this requirement not being met is that these filters require replacement every 3 months. The specification originally wanted the device to require maintenance only yearly. A way the team could have improved this requirement being met is by making a possible cage for the device where the filters would slide in out to make this change easier. But it is unlikely to get a filter that does not need to be changed regularly and still meet the ventilation requirement.

DISCUSSION

Problem Definition

If the team was allotted more time and resources to further advance the definition of the problem, research would be conducted surrounding the modification of central climate control systems. One key aspect of the selected concept is that it works independently of central systems. However, if the team could identify that the main problem lies within lack of ventilation by the central systems, then another solution space may open up involving the addition of filters to heating and/or cooling systems. Research in this area may also determine that central heating and/or cooling systems may be ineffective and another problem in and of itself. Furthermore, a question that the team may explore is "How well do central heating and cooling systems do their job in K-12 schools?" This could be done by examining the performance of central systems at local schools, and compare the performance to that of well-funded office buildings. Another question that the team could explore is "What other factors cause virus transmission to be relatively high in K-12 classrooms?" This could lead the team to other need statements that would aid in slowed transmission.

Stakeholders for this project include the design team, students in K-12 schools, faculty in K-12 schools, and the University of Michigan HVAC Committee. The students and teachers are primary stakeholders because their lives are directly impacted by the problem at hand. They also fall into the category of customers for the same reason. The design team and the U-M HVAC Committee would be considered tertiary stakeholders because they are not within the context of the problem but they have the ability to influence the development of a solution. The U-M HVAC Committee would be considered Resource Providers because they gave the design team valuable information and insight to help define and address a need within the problem context. The design team would be considered a beneficiary because the success of a solution would result in their profit. Some other stakeholders include box fan producers, paper air filter producers, and competing ventilation system producers. These would all be considered secondary stakeholders because they fall in the context of ventilation, but may not be directly impacted by the lack of proper ventilation in K-12 schools. A solution to the problem may positively or negatively impact each of the secondary stakeholders. Another secondary stakeholder is the local communities near K-12 schools. These people may be affected by the problem if students or faculty bring the virus out of the school. The government would be a tertiary stakeholder because they oversee public schools and monitor the status of the ongoing pandemic. Government influence may aid in the implementation of a solution.

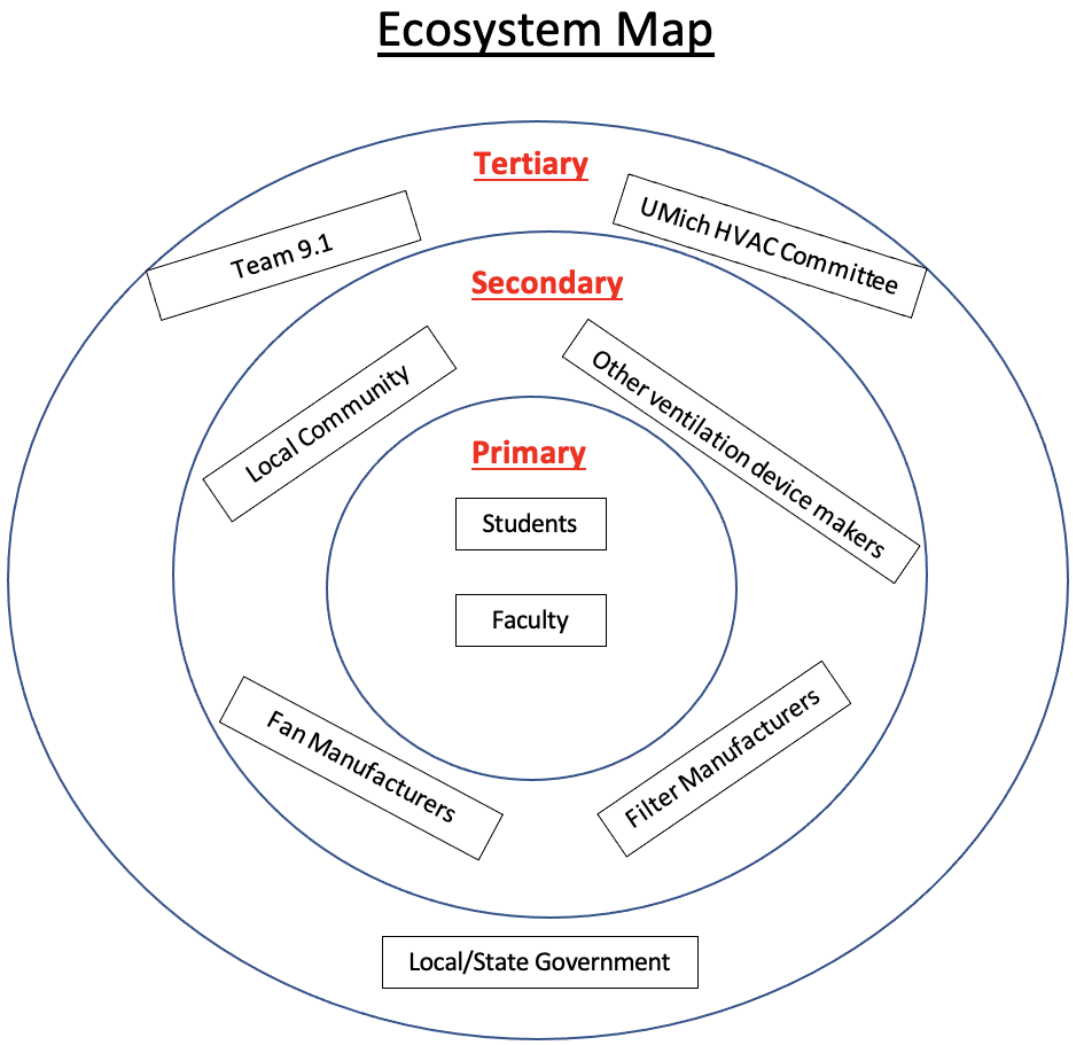


Figure 17: Ecosystem Map

Design Critiques

Following the testing of the group's initial design, they were able to see some of the positive characteristics of the design, but also some areas of possible improvement. Starting with the positives, the design is extremely inexpensive. The materials bought used only a fourth of the $300 budget leaving lots of leeway for potential upgrades. The initial design can also be made by nearly anyone given the simplicity of the materials and the easy assembly process. The materials consist of 4 filters and a common box fan. These were assembled using duct tape. Lastly, operating the device is very simple. No additional controls were added, so depending on the preferred level of air flow, the dial on the box fan could be turned higher or lower to control that.

The group also acknowledged lots of room for possible improvements. Some of the main weaknesses the group found were the stability of the design and the difficulty conducting maintenance after assembly. The group has an idea on a possible solution to these weaknesses. The idea is a frame for the entire design. It could be 3-D printed and would have slots to slide the filters into and provide a cover for the fan giving it a cleaner look. This would allow for easy maintenance on the filters by simply sliding them out and inserting a new one. Lastly, It will also be more durable than the current duct tape assembly method given that the preexisting frame will be more sturdy. Another aspect the group wants to look further into is the air flow through the device. Given the remaining $225, the group would potentially plan on investing in a stronger fan or another device to improve in this area.

Lessons Learned

The group learned a lot about the design process as they completed this project. During the concept generation phase, the group developed lots of ideas ranging in complexity. As the design selection process was conducted, the group realized that most of the higher complexity ideas weren't able to complete the requirements as well as some of the simpler ideas. Although these ideas were much more interesting, the simpler ones were much more effective. Moving forward, the group learned to not overthink problems too much, because the most simple answer could be the best.

The group also learned a lot about time management and planning skills. The Gantt chart was a very effective tool for the group. It helped keep the team on track and aware of all that needed to be done every week to achieve their final goals. The chart was also beneficial in that it took into account possible challenges that may arise causing delays, while still allowing the group to accomplish everything they wanted to. The group learned how important it is to plan time wisely and also the importance of anticipating challenges arising.

RECOMMENDATIONS

Going forward with this project, the group has some recommendations on what to do to continue advancing. Starting with possible areas of redesign, a sturdier frame would really benefit this design. Currently, using duct tape as a seal is not the most effective way to connect filters. It is not exact which leaves gaps for air to escape reducing airflow. Duct tape is also hard to disassemble when filter changes are needed. This frame could be 3-D printed with a strong plastic material and would cover all sides of the device. It would have exact fitting grooves where the filters would be slid into and could easily be slid out when maintenance is required. The plastic would also be significantly more durable than the duct tape in maintaining the structure of the device as a whole from possible incidental damage. Lastly, the frame would provide a cleaner look, giving the primary users more faith in the device's capabilities. Following this redesign, the next aspect that should be looked into is providing a stronger airflow. Although the current design passes the airflow requirements, additional money from the budget could be used to purchase a stronger fan or a filter that allows for better airflow without sacrificing effectiveness.

Following this redesign, further testing should be conducted. The anemometer test should be conducted again to ensure that the airflow still meets the given requirements, or is better than before if a stronger fan is purchased. After this, CFD software would also be very beneficial to use. This software would be able to model the airflow in a room, and help detect the most efficient location for the device within a classroom.

Once this portion of testing is concluded, the group would recommend testing in an actual setting and getting feedback from students and faculty to see any possible areas of improvement before final reiterations are done.

CONNECTION TO BLOCKS

Problem Definition
The problem definition block was extremely useful as the group developed their requirements and then the accompanying specifications. From the block we learned the importance of stakeholder needs and wants. The U-M HVAC Committee was crucial in helping the design team develop initial requirements based on their previous experience in the field and also in helping refine the specifications that were developed as a result. From there, the block also exemplified good examples of specifications to mimic when beginning this process. (DR0) As a result of the interviews the team completed with their stakeholders, they developed a plan which includes questions to ask as well as guidelines on the structure of the conversation. From the blocks, the strategies of not interrogating the stakeholders, asking open-ended questions, and trying to adopt interviewee's language presented by the blocks were used to come up with these interview questions presented in Appendix A. (DR1)

Social Context
In the design process, social context is imperative to developing a solution that effectively solves the problem. Prior to the DR0, the needs of primary stakeholders such as the teachers and students using a classroom and the administration that would pay for a solution informed our definition of the need statement. Similar considerations of stakeholders and social and economic factors were used to formulate the other need statement ideas. Defining requirements and specifications in DR1 required the team to consult the HVAC team at the University of Michigan. This group is a Complimentary Organization that informed a great deal of the conversion of requirements to the final specifications. The HVAC team was again consulted regarding safety concerns of some generated concepts during the down-selection phase for DR2.

Library
The library block was beneficial to the group in finding additional information for their needs statement. Going through the block, the group learned how to navigate the library website and who to reach out to if they were struggling to find something. The library website was used to find patents, standards, and additional research articles. This source was used consistently throughout the project. (DR0, DR1, DR2)

Inclusion and Equity
The group used information taken from the inclusivity blocks in the needs filtering stage. A significant amount of time was spent identifying key stakeholders in the project to make sure the filters were relevant to them. Adopting a beginners mindset was something the group tried to keep in mind as the needs filtering process was performed.

The team consisted of five men and no women, which could have narrowed the approaches the members were interested in taking throughout the project. Four of five members are Caucasian, while the fifth is of South Asian descent. Three members of the group are originally from the

Detroit Metropolitan area, one is from suburban Chicago, and the other is from Annapolis, Maryland. Geographic differences are thus the most significant differences among the group. All five members attended public schools, but the differences between them caused the group to carefully decide on the next steps. As a result, at each juncture in the course of the project, cultural differences resulted in the group making deliberate choices for how to move forward. One main similarity that helped here was that each member was also raised to be respectful of others' viewpoints and value consensus of the group.

Ethics

When working through the design process, the team needed to consider the ethics of every decision that was made. The information from the ethics block was helpful during several phases of the design process, including DR0 and DR2 material.

One problem that the team faced that involved ethics was choosing a needs statement for DR0. In the block, it is mentioned that some engineering disasters can stem from making decisions based on priorities other than human welfare. Many of the need statements that the team considered had potential to save lives with respect to COVID-19. Other needs were added simply out of team interest, and might not have been as effective at protecting people. This brought up an ethical dilemma, and the team chose a need that landed in the middle ground.

Since DR1 involved finding requirements and specifications that adequately meet the need statement, there were no important ethical decisions to be made.

The team used Utilitarianism when making some decisions regarding ethics. This means that the "right" decision created the greatest good for the greatest number of people. An example of the use of Utilitarianism was during preparation for DR2, when considering the location of the ventilation system within the classroom. One benefit to keeping the system away from the center of the room is that students and teachers may be less likely to trip and hurt themselves. However, more people may benefit to a stronger degree if the system is in the center if the ventilation effects are greater in this location. Due to lack of testing, it is difficult to make that claim ahead of time, but slowing the transmission of COVID-19 from better ventilation may help more people than preventing a handful of people from tripping. Thus, the more ethical decision would be to place the ventilation system in the center of the room.

Environmental Context

The group took a lot of information from the environmental context block when considering possible solutions. The block discussed strategies in making the concept sustainable. With the idea targeting the sustainable development goal good health and well being. Trying to help the well being of individuals at all ages with reducing COVID-19 transmission. This aspect of the block was used throughout the design process. For example, considering well being was first addressed in the selected need aspect in the beginning (DR0). Thinking about a need that would help the well being of individuals around the team and in lower income areas is what led us to the selected need making this a priority throughout the need selection process. Addressing the sustainability aspects of the environment, society, and economy to make sure the concept is able to last. This component of the block was used a lot during the concept filtering process as well as helping the team develop the requirements and specifications (DR1,DR2). For the environment aspect the team considered the ideas that would affect the ozone such as UV light fans could impact the environment negatively eliminating that idea. Then, looking at society impacts trying to consider if the idea would be able to provide equal opportunity to be able to use it in all different incomonic settings. Finally, looking at the economical aspect of the block, considering aspects of the idea to make it profitable for companies. The team looked at this aspect by doing calculations to minimize the cost of the product and finding a need for it in all locations around the United States. Addressing these sustainability ideas that the block presented helped the team filter down to the selected concept. The team believed that the final concept could help the wellbeing of others, have minimal environmental impact, and become profitable enough to be sustainable in the market.

Concept Exploration

The group used a lot of information from the concept exploration learning block to begin their concept generation process. Brainstorming was a unanimous decision for a method to be used, but other potential methods were unclear. Following the completion of the concept block, the group felt significantly more confident using the morphological analysis method as well as the TRIZ method. (DR1) Throughout the concept selection stage of the project, the team employed multiple tactics in order to eliminate unviable concepts. One such tactic came from the blocks learned in class. This tactic was the gut check. This was completed by writing down any barriers or challenges they see with the potential concept. The team then investigated if these barriers could be overcome. If so, the concept would pass. If the concept could not be adjusted to pass its barriers, the concept would be scrapped. This was very effective and allowed the team to reduce the number of viable concepts all the way down to six concepts. This then allowed the team to move further into the engineering analysis phase in which back of the envelope calculations. This helped the team eliminate more concepts, helping them ultimately reach a final concept. (DR2)

Engineering Analysis

The Engineering Analysis block helped the team create an analysis and testing plan. Engineering analysis was used by the team to help reduce the generated concepts to a final one or two. The team started with simpler methods of engineering analysis and then decided to use more advanced methods after. Back of the envelope calculations were used for the concepts that could be evaluated using this method. This narrowed our concepts to one final method. The group used more advanced physical testing methods to verify requirements such as air flow and noise level. With one of our specifications being related to safety, risk management overview was also a method we kept in mind while going through this process. (DR2)

Verification & Validation

When creating tests and looking at good strategies, the block content was used often in deciding what type of testing would be most beneficial. The block discussed many different types of tests that can be used. The tests that are discussed center around either more user oriented or more technically oriented. First, when looking at ways to test the ability to ventilate air requirements, the team knew a physical test would be most logical to showcase this. But then some other necessary requirements such as usability and safety would tend to have more user orientated tests discussed in the blocks. Some other tests that took place were inspection testing by both the team and stakeholders. The block content that discussed how to use verification and validation to help build on previous parts of the design process. The team used this strategy when trying to go back and critique design issues. This strategy also helped optimize the design.

CONCLUSION

The team chose to address a problem associated with the ongoing COVID-19 pandemic. There have been nearly 15 million cases reported in the last six months, and this is only getting worse [4]. The vaccination rate has started to slow and better ways to slow down the pandemic are needed, especially in schools in low-income communities where the pandemic is disproportionately worse. With this starting point, the team conducted research on needs related to COVID-19 specifically focused on low-income communities. Forty-five need statements were created and the needs filtering process began.

Three filters were used in the process. Filter one focused on eliminating needs that lacked team interest or did not require a design and build process to complete. The second filter aimed to eliminate needs that were not feasible for any reason. This could be related to cost, location or another similar concept. The final filter utilized a Pugh chart with criteria specific to the project to gauge the value of each need. The specific criteria included stakeholder impact, availability of resources surrounding the topic, market size, solution landscape, post COVID-19 stakeholder impact and market size, and lastly team interest. Using this process, a final need was selected: "There is a need for a low-cost and effective way to ventilate classrooms to deter the transmission of the COVID-19 virus in K-12 schools in the United States."

In compliance with WHO recommendations and current market standards, a set of requirements and specifications were developed and can be referenced in Table 5. While these requirements and specifications are relatively complete, they are subject to change in the coming weeks as the team's knowledge of the problems increases. The team found that current ventilation and related systems were insufficient in meeting the developed requirements and specifications to address the selected need.

The concept generation phase followed, and the team generated over 100 concepts from brainstorming, morphological analysis, and design heuristics strategies. From there, concepts were down-selected with a three tiered process that considered feasibility, a gut check, and engineering analysis. As a result, the final concept of a box fan and multiple filter combination unit that would stand alone in a room was determined.

To further develop the final concept, the team has constructed a full-scale medium-fidelity prototype of the design. Prototype testing using an anemometer and microphone determined that the design could meet the airflow and noise level requirements. Further testing is needed to determine the safety, usability, and aesthetics of the design. More rigorous methods of engineering analysis including using an air flow hood or using CFD software to model the air flow created by the design could yield more reliable airflow results if needed in the future. Other future plans may include building a cage for the entire product to increase safety and protect the device. This design addition could also make maintenance of the product quicker and easier.

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BIOS

Saahith Mummadi

I am currently a senior studying mechanical engineering with a minor in math. I am from Northville, MI which is about 30 minutes outside of Ann Arbor. I typically favored math and science classes over other classes. I liked the thought process behind these classes and being able to use my problem solving skills and this led me to choose to study engineering. My high school offered us the ability to take CAD classes and this really got me more interested in choosing mechanical engineering as a major. I have had a few previous internships in a wide range of fields. I was able to intern at a vehicle testing lab my freshman year and learn a lot about different parts of cars, hydraulic testing and vehicle standards. This past summer I was very lucky to get an internship with BASF, a large chemical company, at their plant in Wyandotte, MI. I learned a lot about process engineering and all the components that go into creating a product. I spent my time working on optimizing production in their steam plant as well as creating dashboards which were able to monitor all of the site's utilities in real time from anywhere on the plant to check for potential safety hazards. Going forward, I'm unsure of what I would like to do, but hope I find something I can be continuously passionate about. In my free time I enjoy playing golf and am a member of the club golf team here at school.

Benjamin Luke

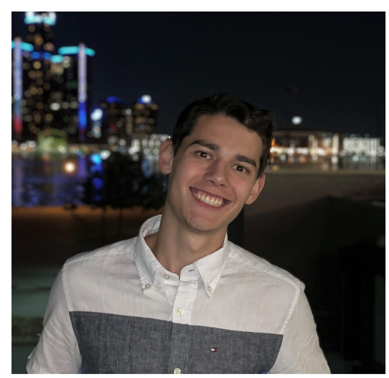
I am from Annapolis, Maryland, the home of the United States Naval Academy. I was interested in studying engineering for the same reason as everyone else: LEGOs. In all seriousness though, I have always been interested in the application of math and science to the real world. I took Project Lead the Way classes in high school, which were a good introduction to engineering coursework. I was fortunate enough to intern at a defense contractor that manufactures gyroscopically-stabilized binoculars for the US Army in the summer prior to my senior year of high school. That internship was a seminal experience in my development as a future engineer and narrowed my focus on mechanical engineering. In particular, I appreciate the broad scope of mechanical engineering. There are many fields inside and outside of engineering for which this major prepares one. I have always appreciated that flexibility. Unlike most of my peers, I do not plan to work in engineering upon graduation. I am in the Naval Reserve Officers' Training Corps (NROTC) at Michigan, and am planning to attend flight school to become a naval aviator. In that community, it is unlikely I will directly apply the coursework I have taken here. I do believe however that the problem solving mindset of an engineer will aid me tremendously in this profession, and in my future beyond the military.

Michael Honaker

I am a senior from Shelby Township, MI pursuing a B.S. in mechanical engineering and minoring in computer science. I have always had a knack for math, physics, and problem solving, and this helped me decide that engineering was something I wanted to explore more in college. I was drawn to study mechanical engineering at U-M by the versatility of career paths that can stem from a mechanical engineering degree. I had the opportunity to intern with Altair Engineering, where I was assigned a co-simulation project modeling an automated targeting system on a military ground vehicle. I am continuing my involvement at Altair Engineering this semester as a Student Ambassador to help students and project teams identify Altair tools as a valuable resource. I am especially interested in autonomous systems, and I hope to apply my background in controls and mechanical engineering principles to the autonomous vehicle industry one day. I am interested in going back to school for an MBA after getting some years of industry experience under my belt, and I am unsure of how long I will stick with a technical engineering role. I hope to land in a role where I can follow my passions and develop my leadership and engineering skills. Outside of my professional interests, I enjoy golfing and skiing in my free time.

Clayton Kidder

Hello, I am Clay and I am currently a senior studying mechanical engineering and minoring in electrical engineering. I am from Davison MI which is located about an hour north of Ann Arbor. I have always been interested in doing puzzles and the problem solving aspects of engineering. Treating problems and projects as a puzzle really have drawn me to pursue a career in engineering. Like most engineers I enjoyed math and science the most in school while growing up, really cementing a career path towards engineering so I could use all these skills. I specifically was drawn to mechanical engineering since the broadness of the field as well as conceptual I understand mechanical aspects much more when compared to chemical or computer engineering. I recently had the opportunity over the summer to work in a manufacturing plant that produced plastic car parts. My future goals are most likely after this year to get a career as an engineer in the automotive industry. I would ideally like to have this first career in a rotational position so I can get a taste of multiple different engineering positions that I could do and figure out the one that I could be most effective in. Then, after a few years in this field pursue a MBA and move towards the management side of engineering.



Hunter Roggekamp

I am currently a Senior majoring in Mechanical Engineering with a minor in international studies. I am from the North side of Chicago so I have grown up hearing about Michigan. I decided to study Mechanical Engineering because I love working with my hands. I have discovered that while I still love to work with my hands I mostly enjoy the problem solving process involved with engineering. I came to this realization through my internship and research experiences during my time at Michigan. After my freshman year, I was abroad in Berlin, Germany doing research on polymers for use in 3D printing. The goal of the research was to develop reliable materials to be used as filament. Then, during my sophomore year, I joined an MDP team where I worked with five other students at Michigan and three engineers at Northrop Grumman. Our project was centered around developing a robotic system which is capable of assembling trusses in a 0g environment. This project was very exciting but had its fair share of challenges which were less than ideal. Going forward I am looking to get into more into the big picture part of engineering. I would like to use my experience and problem solving skills to look at problems from above rather than from the ground level. This may be in a managerial role or in something such as consulting. Either way, I feel that everything I have done up to this point in Mechanical Engineering will be extremely beneficial to me in my future career and I can’t wait to get started.

APPENDIX A: Interview Questions For HVAC COVID-19 Meeting

1. Which type of location in the area has the worst type of ventilation? (ie dorms, classrooms, study rooms, nursing homes)
2. What similar ventilation devices are being used on campus currently? How much do these systems cost? What is the amount of air ventilated per hour?
3. Do you have any access to test the amount of air a potential prototype ventilates?
4. Are there any general size requirements or other specifications that could be helpful for our design?
5. Do you possibly have any access to survey students who stayed in quarantine houses?
6. Would you be willing to meet with us like this bi-weekly?
7. What are some strategies and methods that you have seen that have helped ventilation for other systems?
8. What methods have you taken to ventilate air specifically for COVID-19?

APPENDIX B: Anticipated Challenges from DR0

Any attempt to solve a large problem in our world will be accompanied by equally large challenges which must be overcome, and COVID-19 is no exception to this. These challenges have the potential to put up roadblocks which may force the project behind schedule. Unfortunately, this project has a short timeline with a rigid end date with the current team. As a result, it is especially important to take into account the potential challenges that may come up throughout the project. Thus far, four such challenges have been identified.

One of the largest challenges of COVID-19 in all respects is its unpredictability in timeline and severity. There is no reliable method to estimate the eventual end point of COVID-19. Although unlikely, it is entirely possible that COVID-19 will be here for years to come. On the contrary, it is possible that the vaccines slow the spread and people wear masks enough to eradicate the virus from being a significant threat to our society within the next few months. With the uncertainty of the virus comes uncertainty within the market. Will it be profitable to spend time and resources developing a product to help slow the spread of COVID-19? If COVID-19 were to begin clearing up within the next few months, this investment of resources would have been for nothing. In order to mitigate this risk, this project team seeked to find a problem which may still need help solving after the virus is significantly prevalent. Ventilation indoors pertains not only to COVID-19 but also to other viruses and even general air quality requirements. Because of this, this project will be relatively robust with respect to this challenge.

Another major challenge associated with this project is the difficulty of finding dedicated stakeholders. While the need being pursued in this project is extremely important and has the potential to affect virtually everyone in the world, finding a stakeholder in this niche subject area has been difficult. First, many of the people who are involved in the battle against COVID-19 effort are extremely busy and difficult to get time with. One strategy that has been employed and will continue to be employed is reaching out to organizations who either work with ventilation or have the potential need for help in this area (ie., facilities managers, nursing homes, quarantine housing managers).

Given the quick timeline of this project, one challenge that will likely come up towards the end of the project is the feasibility of prototyping and testing. In order to develop a prototype the team will need to complete an entire concept phase, decision phase, design phase, and build phase. Even if the build phase is reached, there will be a requirement of time to order the items which will not be quick. Following this, if the build is completed, a location and test method must be developed. In order to counter the extra time required by component ordering time and testing setup, these aspects of the projects will begin during the design and construction phase respectively. This will minimize the amount of wasted time between project phases in turn maximizing the potential to complete all desired components of the project.

The final area in which the team anticipates some challenges is with their team's past experience in the ventilation area. The team has had minimal experience with ventilation. Fortunately, this is a relatively simple concept, so the team will be able to complete the project without extensive knowledge in the subject area. In order to gain as much knowledge in the subject area as possible, the team is completing a rigorous research stage to collect as much information as possible. They have also reached out to multiple faculty on campus who work with ventilation at the University of Michigan. The hope is that the knowledge the team gains in their research in combination with the expertise from the University of Michigan employees will be sufficient to complete the project.

A project such as this which is based on such a short time frame is bound to have some challenges. While there is no way to avoid these challenges completely, the team is being as proactive as possible in understanding the potential challenges and developing plans to reduce the effects of these challenges. The hope is that with good planning and prompt execution the team will be able to reach a final prototype which can be passed on to a later team to further develop a solution.

APPENDIX C: Project Plan from DR0

Up to this point, the group has mainly focused on needs selection and filtering. The first week was spent creating a strong problem definition to begin finding needs. From there, a week was spent reviewing sources and doing external research to develop a large set of needs. Next, the 45 needs went through the team's three step filtering process to eventually lead to the final selected need. This information was all presented in the DR0 presentation.

The current tasks at hand revolve around the concept generation stage of the project. Initial research and drafts have been completed on requirements and specifications; however, developing these items is an iterative process and will require additional edits down the road. Some potential stakeholders have also been contacted. This included facilities managers and a committee which works with the HVAC system at the University of Michigan. The team has also identified some additional stakeholders who will help give insight into the problem including students who were previously housed in COVID housing and nursing home managers. The team is currently working to contact these stakeholders to set up interviews. As a result of the upcoming interviews, the team has decided to begin developing an interview plan which includes questions to ask as well as guidelines on the structure of the conversation. The strategies of not interrogating the stakeholders, asking open-ended questions, and trying to adopt interviewee's language presented by the blocks were used to come up with these interview questions presented in the Appendix A.

For the coming future, the majority of time will be spent diving deep into the selected need and developing a strong set of requirements and specifications that encompass all that is required for the ventilation system. From there, concept generation will begin with a group brainstorming session in which the team will cast a wide net and develop as many ideas as possible. Then, the 25 most promising concepts will be selected. Each member will take control of five of the concepts and make preliminary sketches. From there, filters will be applied to reduce the number of concepts below 25 ideas. Using a similar process to the one used for needs filtering, the sketches will be narrowed down to five final sketches through a filtering process. The team has not yet chosen which filters will be used for this procedure. Refined sketches for these five concepts will then be created with detailed labeling.

Once the final five concepts have been selected, each team member will take ownership of one concept and create a low fidelity prototype. At this point, the team will have gathered enough information about each concept that a Pugh chart can be used to select a final design. The team will work together to score each of the concepts and ultimately select the final design. This will take up a majority of the time until DR2 and based on progress, the team will edit the timeline from there. A more in depth project plan can be found below in figure 14, the group's gantt chart.

GANTT CHART

PROJECT TITLE Team 9.1 Capstone Project **COMPANY NAME** Nine Point One

DR0 - DR1

10/4/2021 | 10/11/2021 | 10/18/2021 | 10/25/2021 | 11/1/2021 | 11/8/2021 | 11/15/2021

TASK TITLE	START DATE	DUE DATE	Lead(s)	PCT OF TASK COMPLETE
Problem definition and need selection				
Needs Selection	9/25/21	10/1/21	All	100%
DR0 Report	9/30/21	10/12/21	All	75%
Meeting with HVAC COVID-19 Committee	10/11/21	10/11/21	Clayton	0%
Reach out to Nursing homes regarding ventilation	9/30/21	10/8/21	Hunter	10%
Survey quarantine housing patients	10/11/21	10/15/21	Michael	10%
Interview Plan Generation	10/9/21	10/10/21	Hunter & Saahith	10%
Meeting with Librarian	10/12/21	10/12/21	Saahith	10%
Project Definition				
Ventilation requirements research	10/5/21	10/11/21	Clay & Ben	50%
Development of final ventilation requirements	10/7/21	10/26/21	Clay & Ben	25%
Specification research for ventilation devices	10/5/21	10/11/21	Michael	50%
Development of final ventilation specifications	10/7/21	10/26/21	Michael	25%
DR1 Presentation	10/18/21	10/26/21	All	0%
DR1 Report	10/27/21	11/2/21	All	0%
Concept Generation / Prototyping				
Team Brainstorming Sessions	10/12/21	10/18/21	Hunter	0%
Each member to provide at least 5 sketched designs	10/19/21	10/27/21	All	0%
Filter down to 5 sketches	10/19/21	10/27/21	Michael	0%
Develop refined sketches for final 5 concepts	11/3/21	11/8/21	All	0%
Create low fidelity prototypes for remaining 5 concepts	11/8/21	11/16/21	All	0%
Use pugh chart to select final concept	11/17/21	11/21/21	Clayton	0%

Figure 14: Project plan leading up to Design Review 1 and the two weeks following

The group plans to use the information learned from the concept exploration while conducting future tasks. An ideation session will be held and the 4P's of creativity will be implemented for concept generation. The three steps of concept evaluation -concept screening, concept evaluation, and concept selection- will be used to eventually reach a final concept design. Specifically, the group plans on spending a substantial amount of time organizing ideas using the organizing principles provided in the block and identifying gaps to ensure key requirements and specifications are met.

APPENDIX D: Complete Gantt Chart

GANTT CHART

PROJECT TITLE	Team 9.1 Capstone Project	Nine Point One

DR0 - DR1

TASK TITLE	START DATE	DUE DATE	Lead(s)	PCT OF TASK COMPLETE
Concept Generation / Prototyping				
Team Brainstorming Sessions	10/12/21	10/18/21	Hunter	100%
Each member to provide at least 5 sketched designs	10/19/21	10/27/21	All	100%
Morphological chart team activity	11/3/21	11/3/21	All	100%
Heuristic concept generation activity	11/3/21	11/3/21	All	100%
Filter down to 6 concepts	11/4/21	11/8/21	Michael	100%
Develop refined sketches for final 6 concepts	12/9/21	11/12/21	Ben	100%
Create low fidelity prototypes for remaining 5 concepts	11/8/21	11/16/21	All	100%
Complete additional research on Idea 1	11/8/21	11/16/21	Hunter	100%
Complete additional research on Idea 2	11/8/21	11/16/21	Clay	100%
Complete additional research on Idea 3	11/8/21	11/16/21	Ben	100%
Complete additional research on Idea 4	11/8/21	11/16/21	Michael	100%
Complete additional research on Idea 5	11/8/21	11/16/21	Saahith	100%
Complete additional research on Idea 6	11/8/21	11/16/21	Saahith	100%
Compare viability of idea 2 and idea 6	11/11/21	11/18/21	All	100%
Break final concept into subsystems	11/18/21	11/21/21	All	100%
Purchase Initial components	11/18/21	11/21/21	Mike and Clay	100%
Conduct design of subsystem 1	11/21/21	11/28/21	Hunter	25%
Conduct design of subsystem 2	11/21/21	11/28/21	Michael	25%
Develop prototype of subsystem 1	11/21/21	11/28/21	Hunter	0%
Develop prototype of subsystem 2 using basic filters	11/21/21	11/28/21	Michael	0%
Compare basic and HEPA filters using single filter places on on fan inlet	11/21/21	12/1/21	Michael and Clay	0%
Use CFD software and CAD designs to test ventalation ability (still have to explore is this is possible)	11/28/21	12/5/21	Michael	0%
3D print initial rough prototype brackets (If applicable)	11/28/21	12/5/21	Hunter	0%
Assemble Final prototype	11/28/21	12/5/21	Hunter	0%
Conduct testing of Final prototype	12/5/21	12/16/21	Ben	0%

Figure 15: Complete Gantt Chart.

APPENDIX E: Brainstorming Session Sketches

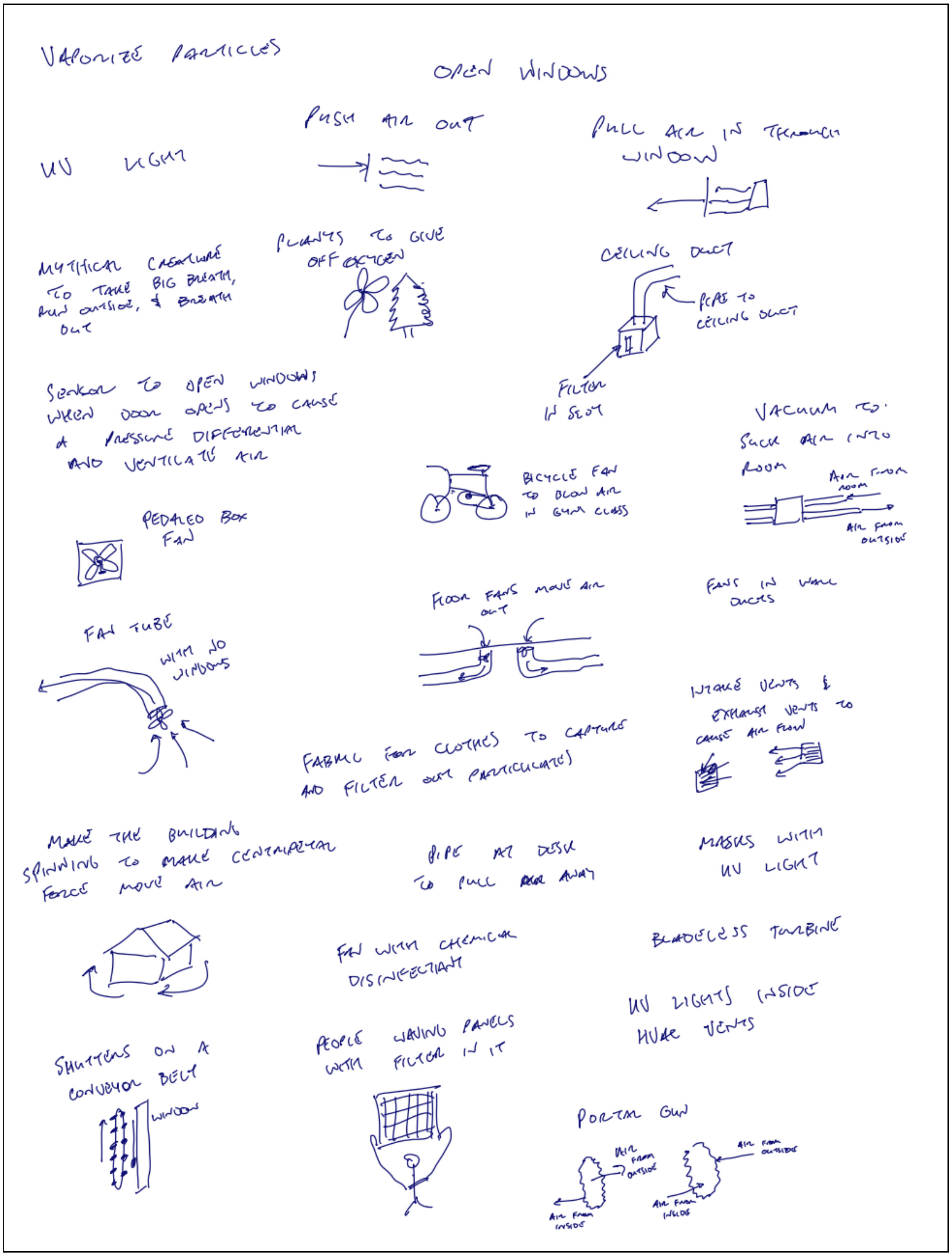


Figure 16: Page 1 of brainstorming session.

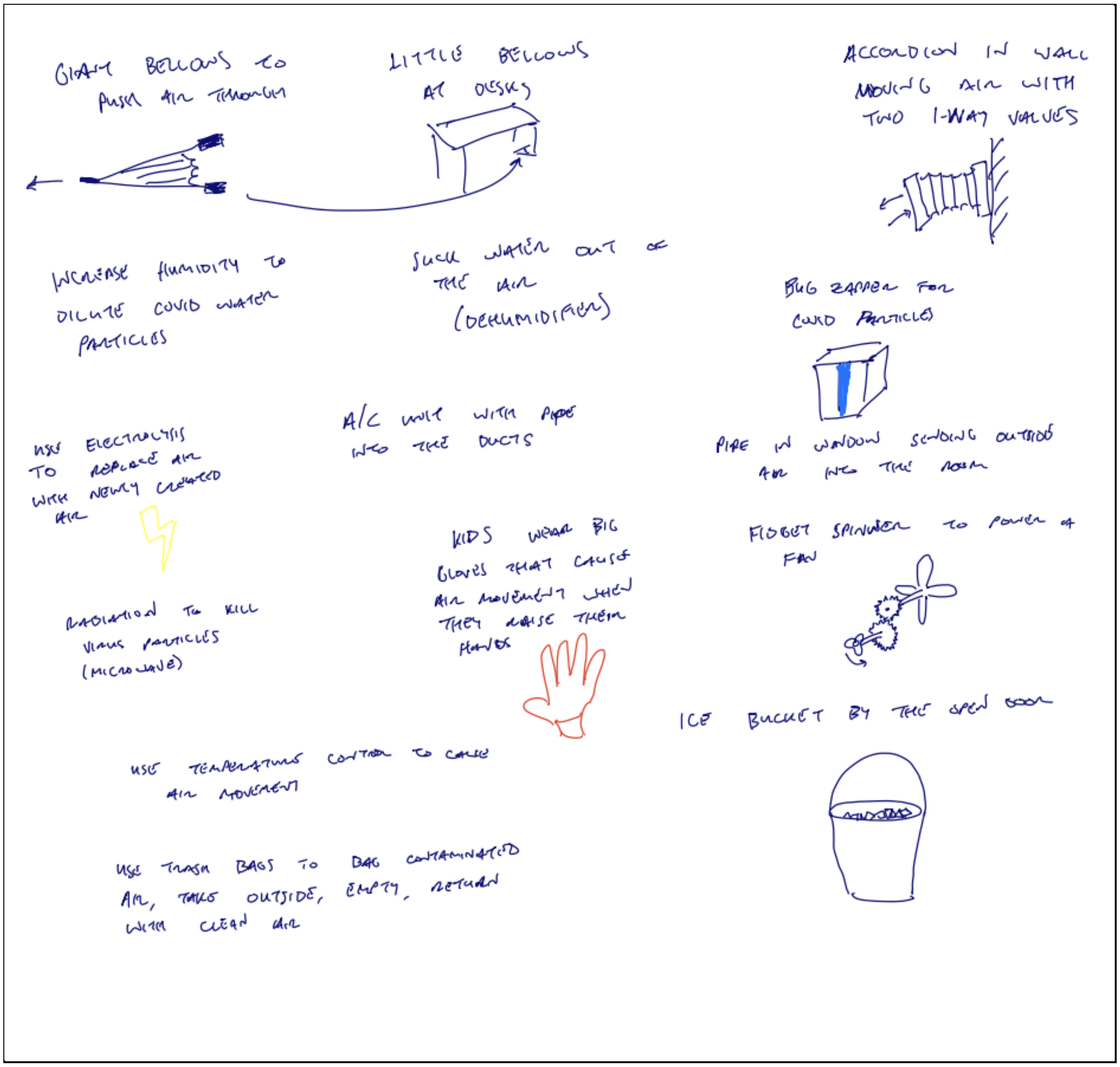


Figure 17: Page 2 of brainstorming session.

APPENDIX F: Anticipated Challenges from DR1

Continued Engagement with University of Michigan HVAC Committee

The team is currently working with the U-M HVAC Committee. The HVAC committee meets biweekly on Mondays and has generously offered to let the design team sit in on the beginning of each meeting. This is very helpful to the team as it allows them to get important information about HVAC systems and their requirements as well as feedback on their completed work. It is a challenge however that this committee only meets once every other week. Thus far, this has not posed too much of a challenge, but once the team enters the design phase, feedback every two weeks will likely be insufficient. In order to reduce the impact of this challenge, the team plans to ask the head of the HVAC committee to meet weekly with the team to give additional feedback. The committee head has demonstrated interest in the team's project and has been extremely helpful thus far.

Requirement and Specification Adjustments

The problem of ventilation with COVID-19 is one that has many potential solutions. As a result, developing all encompassing requirements and specifications that do not restrain solutions is quite difficult. The team has put a significant amount of time into developing the current requirements and specifications, but they are subject to change. It is uncertain whether or not the current requirements and specifications will suffice in addressing the need as the team continues to learn more about the problem. In the case that the team would like to adjust their requirements and specifications, they plan on working with their stakeholder, the U-M HVAC committee, as well as Professor Sienko to get their input on the adjustments.

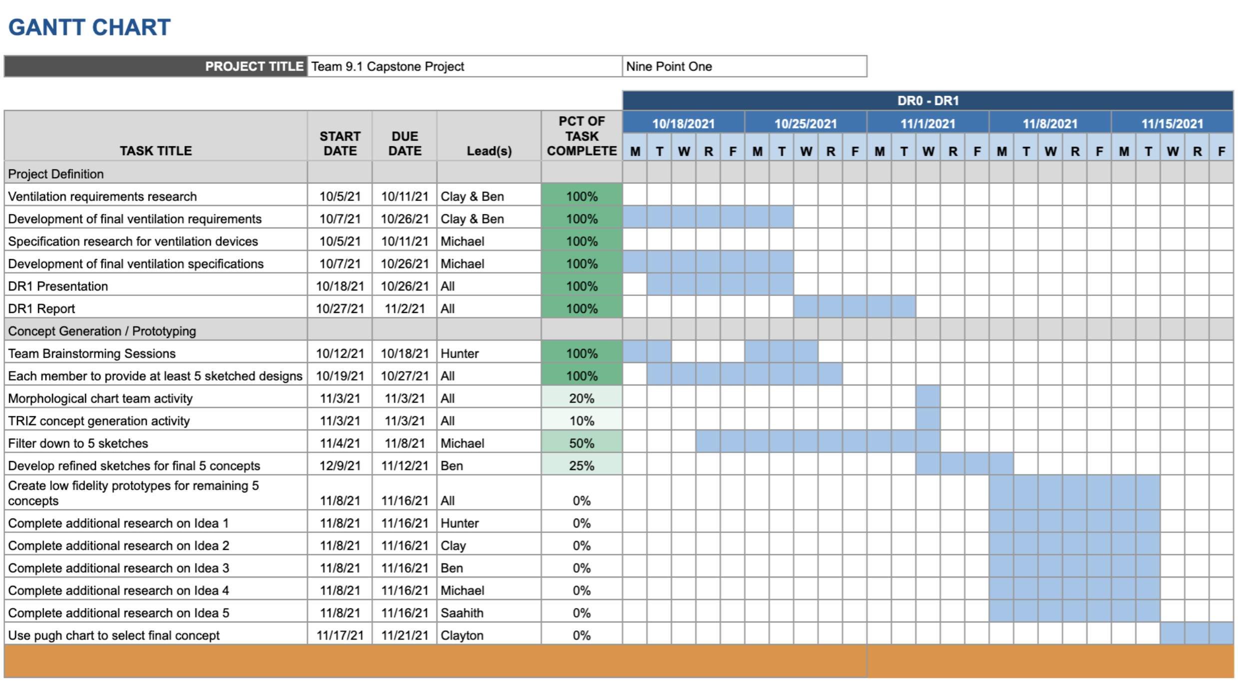
Prototyping Time Constraint

Since the beginning of the semester, the design team came into the project with the intent of designing and prototyping a device for this need. The opportunity for the team to reach this goal is shrinking. The timeline for the project has fallen slightly behind schedule. This means that the team may not have the time to create a final refined prototype. In the case that the team is too time constrained at the end of the semester, they will develop a low fidelity model which can be made in less time.

APPENDIX G: Project Plan from DR1

Thus far, the team has made it through the research and problem development phases and begun the concept generation phase. The main focus for the coming week will be around completing concept generation and concept selection. Since the last update which can be referenced in Appendix C, the team has made significant progress on the development of requirements and specifications. Following this the team conducted in depth research into each specification and used primary and secondary sources to quantify values which would definitively fulfill its parent requirement. As discussed in the anticipated challenges section, these requirements and specifications are subject to change and will be revisited in following weeks to ensure their validity. One way that under-developed requirements and specifications will be filled in is through meeting with the Joanna Thielen, the librarian for the BME, ME, and ISE departments. This meeting has not been scheduled yet because much progress has been made recently through secondary research, but the team is looking to schedule the meeting soon to polish off the current requirements and specifications.

Looking forward, the team will focus mainly on the concept generation and selection. The team has completed a brainstorming session and has created a plan to work on the TRIZ and morphological analysis items. The exact dates for these can be seen below in the condensed version of the team's Gantt Chart.



TASK TITLE	START DATE	DUE DATE	Lead(s)	PCT OF TASK COMPLETE
Project Definition				
Ventilation requirements research	10/5/21	10/11/21	Clay & Ben	100%
Development of final ventilation requirements	10/7/21	10/26/21	Clay & Ben	100%
Specification research for ventilation devices	10/5/21	10/11/21	Michael	100%
Development of final ventilation specifications	10/7/21	10/26/21	Michael	100%
DR1 Presentation	10/18/21	10/26/21	All	100%
DR1 Report	10/27/21	11/2/21	All	100%
Concept Generation / Prototyping				
Team Brainstorming Sessions	10/12/21	10/18/21	Hunter	100%
Each member to provide at least 5 sketched designs	10/19/21	10/27/21	All	100%
Morphological chart team activity	11/3/21	11/3/21	All	20%
TRIZ concept generation activity	11/3/21	11/3/21	All	10%
Filter down to 5 sketches	11/4/21	11/8/21	Michael	50%
Develop refined sketches for final 5 concepts	12/9/21	11/12/21	Ben	25%
Create low fidelity prototypes for remaining 5 concepts	11/8/21	11/16/21	All	0%
Complete additional research on Idea 1	11/8/21	11/16/21	Hunter	0%
Complete additional research on Idea 2	11/8/21	11/16/21	Clay	0%
Complete additional research on Idea 3	11/8/21	11/16/21	Ben	0%
Complete additional research on Idea 4	11/8/21	11/16/21	Michael	0%
Complete additional research on Idea 5	11/8/21	11/16/21	Saahith	0%
Use pugh chart to select final concept	11/17/21	11/21/21	Clayton	0%

Figure 18: Condensed Gantt Chart. Complete Gantt chart can be seen in APPENDIX D.

The team will be completing the morphological analysis followed by TRIZ on Wednesday, November 3. After this, the team will combine all of the concepts and put them through a filtering process which has not yet been developed. The team will filter down the concepts to the five most promising concepts through the filtering process which will then be researched the following week. Each team member will take the lead on one of the concepts. The team will come back together at the end of the week and conduct a pugh chart analysis which will allow them to pick a final design.

This marks the time that the team is ready to enter the concept design stage. Given the high variability of the timeline in this project, this stage of the project will be evaluated once the team has a final concept. The final scope of the project will be discussed with stakeholders and the desired outcome at the end of the term will be determined. At this time the team will create an in depth plan for the ending stage of the project.

APPENDIX H: Open Window Electricity Calculation

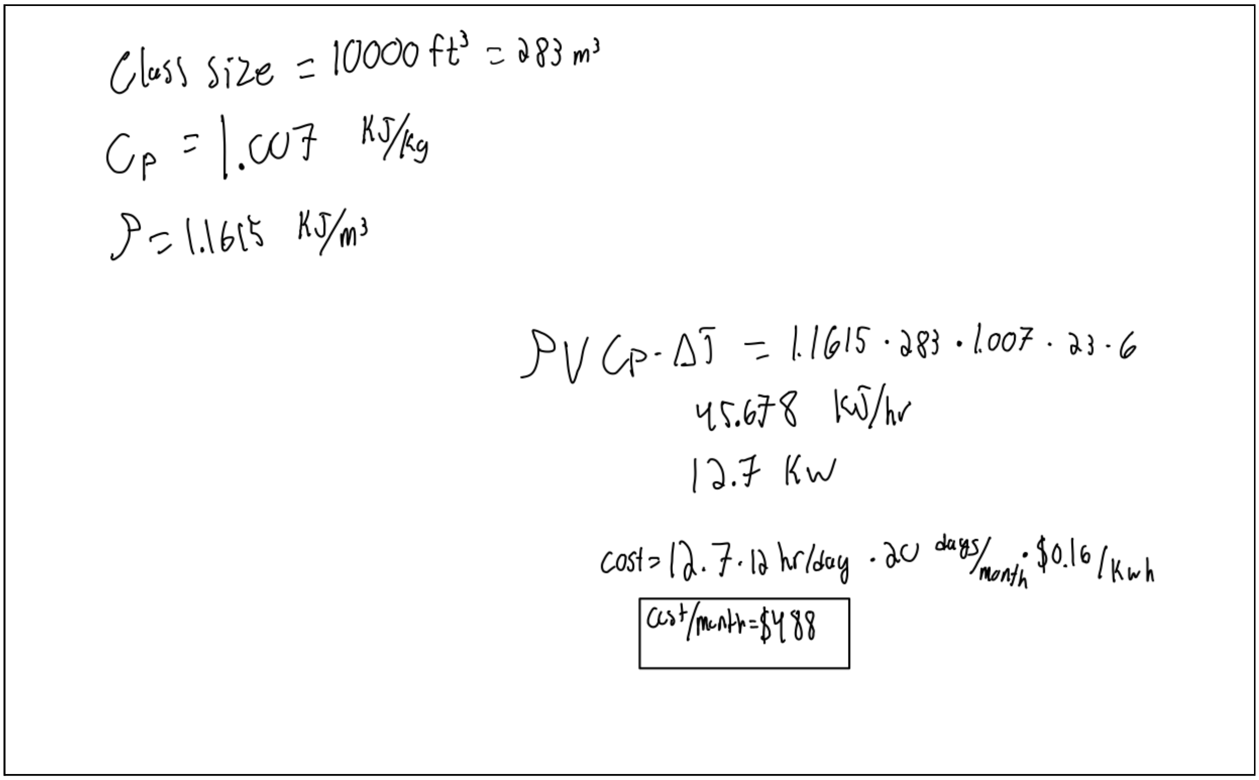


Figure 19: Math calculating electricity cost of using outside air to ventilate indoor classrooms

APPENDIX I: Anticipated Challenges from DR2

Developing a method to reliably measure air flow rate from a prototype design

One of the team's requirements involves the solution being able to filter sufficient air following CDC recommendations. In order to prove this requirement and subsequent specification true, the team will need to measure the flow which the system produces. There are multiple ways this can be done ranging from a complicated closed test in a lab to a simple anemometer. The trouble is finding a good balance between time, cost, and reliable results. A closed test in a lab is most likely to produce consistent results, however, will likely cost too much and be difficult to complete within the given timeframe. The anemometer is cheap and will produce rapid results, however is far from the most reliable testing method. Given the time frame the team will likely use an anemometer testing method; however, the team is still working with the HVAC Committee to see if they have additional resources which can be used.

Failure to meet a single or multiple requirements or specifications

The problem of ventilation with COVID-19 is one that has many potential solutions. As a result, developing all encompassing requirements and specifications that do not restrain solutions is quite difficult. The team has put a significant amount of time into developing the current requirements and specifications, however, we have done so considering the fact that some of these requirements and specifications may not ultimately be met. The team has found that some requirements counteract other requirements.

Reaching adequate air flow without excessive noise

An example of requirements that contradict each other are the noise, cost, and air flow requirements. It is difficult to find a fan which is quiet and produces sufficient air flow at a low cost. If it has enough air flow, it is likely too loud. If a fan has enough air flow and is quiet enough, it is too expensive. If it is quiet and cheap, it will not produce sufficient air flow. Because of this, the team will need to sacrifice the success of certain requirements. This is where the requirement priorities developed earlier in the project will come in handy.

Effectively capturing the safety requirement with specifications

With the main target area being K-12 schools, there are a lot of safety precautions that must be taken with the device to make sure schools are comfortable using it within their classrooms. With younger children especially, the team must ensure that spinning objects within the fan are completely out of reach. This is covered in the specification for the safety requirement; however, it is difficult to be certain that the product can be considered safe just because the fan blades are unreachable. The team has faced some challenges classifying all potential hazards into specifications.

APPENDIX J: Project Plan from DR2

Thus far, the team has made it through the research, problem development, and concept selection phases and begun the prototyping phase of this project. The main focus for the coming week will be around completing initial prototypes and testing. Since the last update, which can be referenced in Appendix G, the team has made significant progress in the selection of a single concept. With this, the team has come up with a plan to create a rough prototype which they can test in order to confirm or fail each of their set requirements.

Looking forward, the team will focus mainly on the prototyping and testing. The team has completed the initial purchasing of prototype components. This involves a standard box fan as well as a variety of standard filters. In the future, the team may need to purchase additional filters to test varying grades of filters as well as an anemometer to measure the flow rates through these filters. This has not yet been completed, but will happen within the next week. A condensed gantt chart of the team's project plan going forward can be found below in Figure 13.

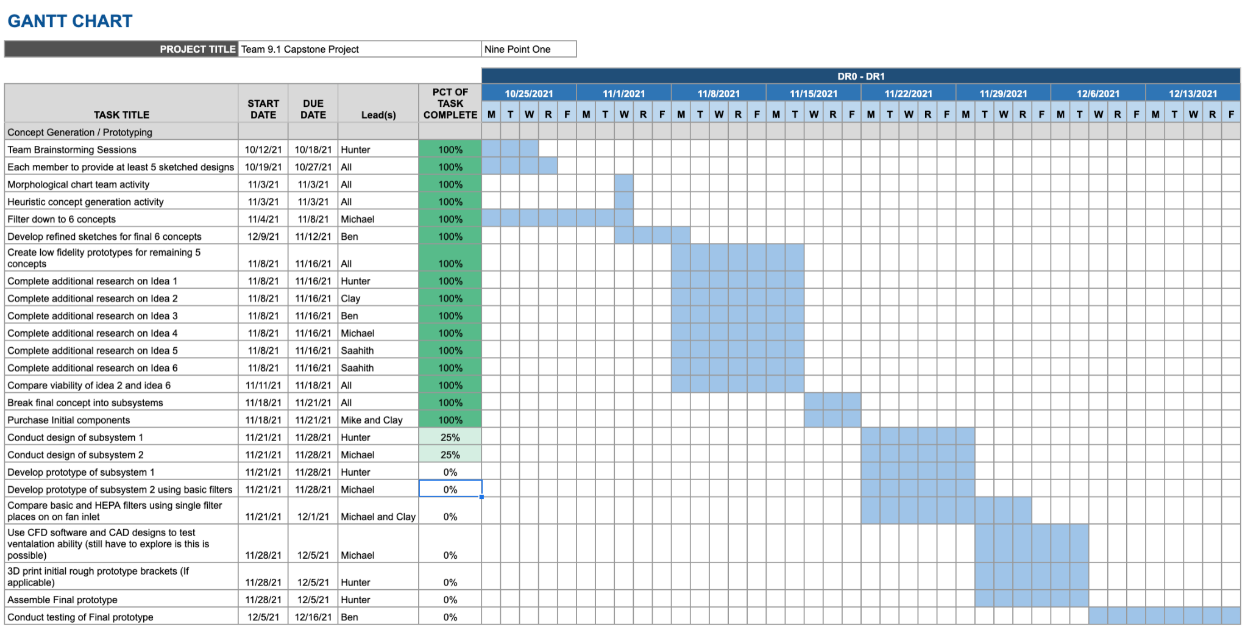


Figure 13: Condensed Gantt Chart. Complete Gantt chart can be seen in APPENDIX D.

With two weeks left the team has developed a plan which, if conducted correctly, will allow the initial prototype to be adequately developed to begin a first round of tests for the prototype. Manh of the specifications which the team plans on testing require very simple testing in order to confirm. These specifications include those within the following requirement categories: inexpensive, portable, quiet and safe. Slightly more complicated testing will be required with remaining specifications which fall under the following requirements: able to ventilate air, aesthetically pleasing, usable. Because these requirements/specifications may require additional time to test, the team may not be able to reach all of them given the time constraints of the project. Because of this the team plans on prioritizing the requirements to ensure the most important requirements are conducted first. The team plans on meeting this week to discuss this and will consult their stakeholders with their final plan.