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Controlling SARS Related Illnesses in the Indoor Environment using HVAC Ventilation Techniques

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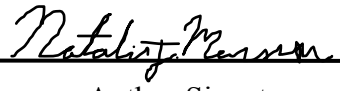
Natalie Mansson		October 3, 2022
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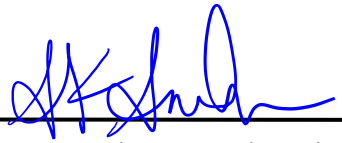
Dr. Anne Anderson		October 2, 2022
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Dedication

For my mother Yvonne Mansson for instilling in me a valuable, distinguished work ethic and a drive to always do better.

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Abstract

The COVID-19 pandemic has brought on a need for better ventilation systems due to the deadly spreading of the SARS-CoV and SARS-CoV-2 illness through the air. As the positivity rate increases sharply, this study is pertinent in the fight against the virus. The implementation of MERV filters and ventilation rates while also understanding respiratory droplets and how they move through the air is an important part of understanding airborne transmission. Much research has been done on MERV filtration and respiratory droplets and their traveling methods in the air, and this research aims to find the commonalities between prior research, and to provide further insight into topic. Offices around the world have been navigating creating a safe environment for their employees to be able to work in person rather than remotely.

Key Words: HVAC, Ventilation, Indoor Air Quality, Air Borne Illness, SARS, COVID-19

Chapter One: Introduction

The COVID-19 pandemic brought to attention our lack of preparedness for fighting deadly viruses and the need for better ventilation systems. Throughout this study, the positivity rate of SARS-CoV and SARS-CoV-2 in the world population increased sharply and new variants were continuing to emerge, making the results of this study critical and timely. An important part of reducing or eliminating airborne transmission is understanding the implementation of MERV filters and ventilation rates while also understanding respiratory droplets and how they move through the air. Much research has been done on MERV filtration and respiratory droplets and their traveling methods in the air, and this research presents a case study on an office of a subcontractor business that specializes in virtual design & construction, engineering, mechanical, fire protection, and electrical construction, building automation, and service & maintenance. The purpose of this case study is to present how this office made it possible for its employees to work safely in the office during the pandemic and presents a possible solution for other offices to be able to have its employees return safely into the office environment.

Chapter Two: Literature Review

An acute respiratory disease became prevent in December 2019 originating from Wuhan, China. (Yuki et al, 2020). The disease spread rapidly to other areas of the world. It was soon realized that the coronavirus was responsible for this outbreak of respiratory illnesses. Coronavirus "was named as the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2, 2019-nCoV) due to its high homology (~80%) to SARS-CoV, which caused acute respiratory distress syndrome (ARDS) and high mortality during 2002–2003" (Yuki et al, 2020). "The mutation of diseases such as the coronavirus mutation are typical, most mutations are not dangerous, but the ones that have proved to be dangerous are the Brazilian P.1, UK B.1.1.7, and South African 1.351" as they "possess features such as, escape from the immune system, bind strongly with ACE2 receptor and may cause more harm" (Md Kamal Hossain., Majid Hassanzadeganroudsari., & Vasso Apostolopoulos, 2021).

At the time this study was published in early 2021, the mutation that had been causing a spike in coronavirus cases was the omicron variant. The difference with this variant was that it lowers the efficacy of the COVID-19 vaccines and antibody therapies (Liu, L., Iketani, S., Guo, Y. et al, 2021). With the continuing threat of new variants emerging, understand the current body of knowledge around the coronavirus and how HVAC systems can help prevent spread of airborne illnesses is of the utmost importance in an effort to reduce the impact of this disease.

Managing IAQ during a Pandemic

Determining keywords that relate to the research was the first step in beginning the collection of information for the literature review particularly to manage indoor air quality (IAQ) under pandemic like conditions. The key words that were used to find relative research are as follows: HVAC, Ventilation, SARS, Indoor Air Quality, and Airborne Transmission. Using those keywords, a search for different publications using the Roger Williams University online database was conducted. The RWU library website uses the following databases: Academic Search Complete, Avery Index to Architectural Periodicals, Business Source Complete, Communication and Mass Media Complete, ProQuest, PsycINFO, and World Cat. Publications that were scholarly journal papers that have been reviewed and published were the resources being searched for. After finding journals that relate to the topic, a thematic synthesis was done to identify themes that relate to the topic and show the relationship between SARS illnesses and HVAC ventilation.

Air pollution can be a "crucial contributor to the transmission of an infection by coronavirus in two ways" (Zhang et al, 2020). The first being the "spread of some airborne viruses (such as measles and influenza) have appeared to increase through ambient fine particles that remain airborne longer, travel longer distances, cover larger areas, and penetrate the lungs much more deeply" (Andrée, 2020). COVID-19 is a respiratory disease and the coronavirus can stick around in "viable aerosols for

hours" (van Doremalen et al., 2020). Different theories of how COVID-19 travels have been formed, but recent studies indicate that it is transmitted through the air.

Airborne transmission between occupants indoors takes place "mainly by the generation of infectious droplets from an infected person, the spread of infectious droplet nuclei indoors, and the inhalation of infectious droplet nuclei by an exposed person" (Ai et al., 2018 p. 500). Human respiration activities, such as breathing, talking, coughing and sneezing, can generate thousands and even tens of thousands of droplets (Ai et al., 2018 p. 500). Experiments indicate that "small droplets evaporate rapidly, and large droplets fall to the ground quickly; however, horizontally expelled large droplets can travel a long distance" (Xie et al., 2007 p. 223). At a low relative humidity, "more droplets and droplet nuclei could suspend in air, increasing the probability of subsequent inhalation" (Xie et al., 2007 p. 223). One often-used approach to estimate the risks associated with airborne transmission of respiratory diseases is the Wells-Riley model (Azimi et al., 2013, p. 2). The Wells-Riley model has been used often for assessment of the risk for infection. Ventilation is widely recognized as the most "influential engineering method for controlling airborne transmission indoors realized from longitudinal studies" (Ai et al., 2018 p. 501).

Ventilation refers to the "process of introducing and distributing outdoor and/or properly treated recycled air into a building or a room" (Etheridge and Sandberg, 1996). Ventilation rate is the amount of outdoor air circulated per unit time, whereas its distribution refers to the "pattern of air movement within a room or between rooms in a building" (Li et al., 2007 p. 3). Low ventilation rates and other building characteristics can lead to "increased incidence of respiratory diseases caused by viruses" (Brundage et al., 1988; Fisk, 2001; Daisey et al., 2003). This exploratory research will study the nature of the existing knowledge of how SARS related illnesses are transmitted. Deductive reasoning will be used to pinpoint a specific conclusion to this issue and corroborate the theory that SARS related illnesses can be prevented using ventilation techniques.

Droplet Size

One of the focuses of literature is droplets, specifically the nuclei size of droplets that come from the respiratory system, and how the bioaerosol transport of these droplets occur. The wells-evaporation falling curve presents the information that "smaller droplets dry out before going too far, while larger droplets are able to travel farther through the air because it takes more time for the larger droplet to dry up. Some droplet nuclei can be suspended in the air for hours" (Kunkel et al., 2017). Figure 1 shows the time it takes the droplet to evaporate based on the diameter of the droplet. One study looked at the emissions of bioaerosol by using organisms that were

"aerosolized under low and high flow rates to simulate breathing and periodic coughing" (Bolashikov et al. p. 978). The important note in this study was that using the model organisms is not an exact replication of the way the human respiratory system goes through breathing cycles. Measurements were collected over one year from January 2015 to January 2016 in an unoccupied third floor apartment. The HVAC system for this dwelling was a central 100% recirculating air handling unit. The tests used four different HVAC filter conditions which included no filter, MERV 8 filter, a MERV 11 filter, and a MERV 16 filter. Active bioaerosol sampling was used to collect particles with five size ranges of diameter. This sampling was also done in four locations being "near range", "short range", "mid-range", and "long range" in a straight direction from the source of the cough. Passive bioaerosol sampling was also done using settle plates set at three different distances. Swabs taken from the plates and the air filters were analyzed.

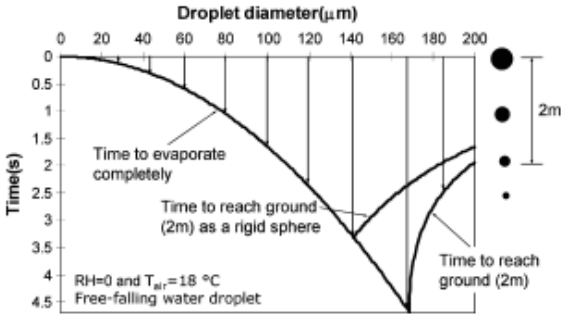

Figure 1: Xie et al., 2020

Ventilation Rates/Air Filtration

Another common theme found in the literature was ventilation rates and air filtration. The higher the air changes per hour (ACH), the dilution of particles in the air is greatly increased. Relating to ventilation rates, air filtration refers to filtering the air with HVAC equipment that contains filters. These filters are MERV filters, MERV stands for minimum efficiency reporting value which determine its effectiveness in stopping contaminants from passing through the filter. Table 1 shows these ratings for a range of MERV filters.

Minimum Efficiency Reporting Values (MERV) for a range of filters.

MERV[a]	0.3–1 μm	1–3 μm	3–10 μm
4[b]	1%	9%	15%
7[b]	17%	46%	50%
11[b]	30%	65%	85%
13	70%	90%	90%
14	80%	90%	90%
15	90%	90%	90%
16	95%	95%	95%
HEPA[c]	99.9%	99.9%	99.9%

Table 1: Azimi and Stephens, 2013

The studies found that the difference between a lower rated MERV filter and higher rated one determines greater filtration at longer distances.

Airflow Patterns and Air Distribution

Air distribution methods include mixing ventilation, displacement ventilation, underfloor air distribution, and downward ventilation. These different methods of ventilation when evaluated have an influence on airborne transmission. Mixing ventilation operates better than displacement ventilation, as droplet nuclei can travel

farther distances indoors when displacement ventilation is used. Downward ventilation is typically used in the hospital setting but can lead to cross-contamination. Personalized ventilation is an advanced air distribution technique to reduce airborne infection in indoor spaces.

Relative Distance

The distance between an infected person and another person increases the chances for exposure. Figure 2 shows that 1.5 meters between the source of infection and potential recipient increases exposure and gives a high risk for transmission.

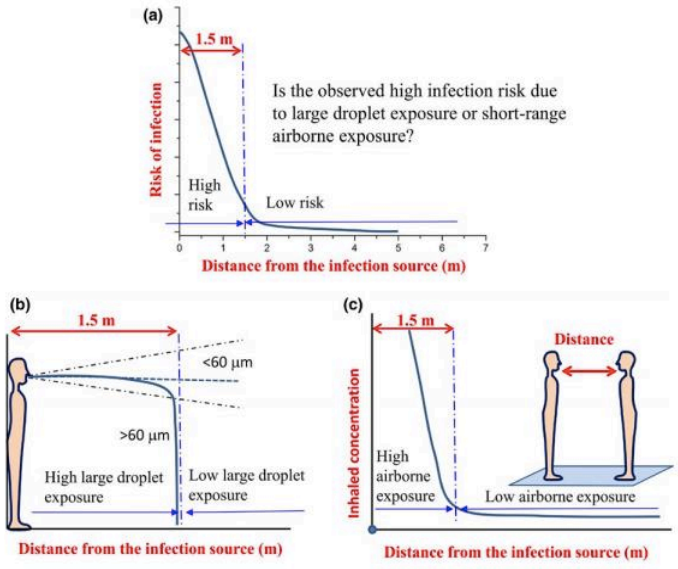

Figure 2: Liu et al., 2007

The farther the distance from the source the less droplets reach the source. Figure 2 shows an experiment done by releasing different sized droplet nuclei towards a manikin at four different distances and where they landed on the manikin.

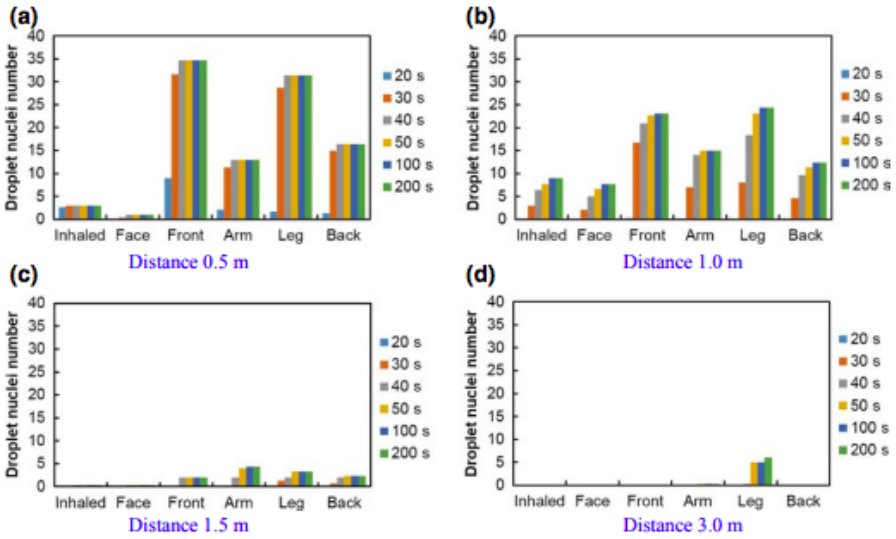

Figure 3: Liu et al., 2007

Different human respiratory activities can also have an effect on how infectious droplets travel. Figure 4 compares normal breathing activities (graph a) flow rate of the droplets and a coughing respiratory activity (graph b). The coughing respiratory activity has peak flow rate at the beginning, while the normal breathing has a peak flow rate of respiratory droplets during the exhalation with a break in between and moves to a negative flow rate during inhalation

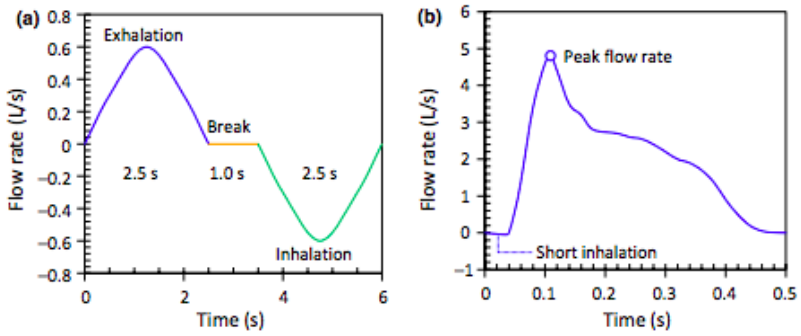

Figure 4: Ai and Melikov, 2018

Relative Humidity

When droplets are released from the person which is a relatively high humidity to a lower humidity environment, typically most indoor environments, the droplets decrease in size and typically only the droplet nuclei are left in the air. Low relative humidity's result in "rapid evaporation and an increase in the abundance of suspended aerosols, and mid-range relative humidity's (40-70%) minimize the survival or viability of bacterial or viral organisms" (Xie et al.,2007, p. 211). Figure 5 shows horizontal distance of a certain droplet diameter tested at three different relative humidities: 30%, 50%, and 70%.

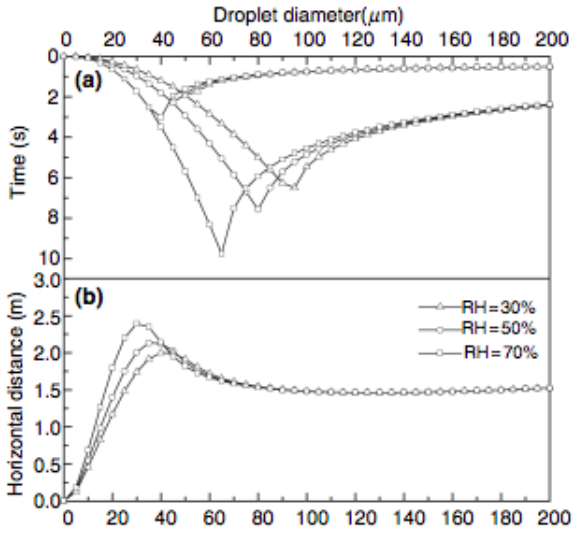

Figure 5: Xie et al., 2020

Chapter Three: Methodology

This study's methodology includes interviews as the tools to build a case study as an example of how a mechanical contractor, Arden Engineering Constructors, LLC. in Pawtucket, Rhode Island responded to the COVID pandemic. According to Arden's website: "Serving Rhode Island and Southern Massachusetts, we are one of the few mechanical contractors with the ability to provide a complete range of services for your building's essential systems. We specialize in virtual design & construction, engineering, mechanical, fire protection, and electrical construction, building automation, and service & maintenance. Our comprehensive offerings provide total system responsibility and supreme customer satisfaction" (ardeneng.com).

Case Study: Interviewing an Expert Company

Interview questions were developed with the following broad topics: financial, social, legal, technical/operational, and a group for other questions. The interview questions were developed with the following research objectives in mind:

- Investigate the relationship between SARS related diseases and ventilation
- Examine how building design relates to effective HVAC ventilation
- Determine what HVAC ventilation techniques are best in reducing the risk of SARS disease related transmission within the indoor environment

This process yielded twenty-one questions. Those twenty-one questions were then condensed down to fifteen questions relating to each of the broad categories. In

addition to those fifteen questions, three introduction/ice breaker questions were developed to understand the participants role in the company.

Participants were chosen based on their knowledge of how the office responded to COVID and also by their knowledge of HVAC systems. Four of the participants were identified as being contributors to how the office responded to the COVID mitigation efforts. One of the participants was present in the office when the modifications were being made. One of the participants has seventeen years working for Arden Engineering Constructors, LLC., two participants have 18 years working for the company, another has 16 years, and finally the participant who has been with the company longest has 33 years.

The interviews were conducted in person and recorded using an app on a smart phone and those interviews were then uploaded to otter.ai, which is a speech to text transcription application that uses artificial intelligence and machine learning. The transcript was then qualitatively analyzed for common themes between all interviews and topics that were mentioned across the board. Using note.ly, a web application that allows the user to create sticky notes in a browser. A sticky note was created for each theme that were mentioned in two or more of the interviews. The themes were then categorized into four main groups. This analysis resulted in common thoughts between interviewees when combatting SARS related illnesses such as COVID-19.

Chapter Four: Findings and Analysis

According to the literature, coughing actions have a higher concentration of nuclei droplets compared to normal breathing. Relative humidity and temperature contribute to how these airborne droplets can survive in the air. Results show that dilution, filtration, UV light, Photocatalytic oxidation, plasma cluster ions, and essential oils can disinfect the air, improving the indoor air quality, and decreasing the risk of airborne transmission. There is also some effect of gravity that occurs for particles going farther distances.

Aerosol transmission seems to be the most predominant transmission route for a multitude of diseases. MERV filter ratings seem to be an important factor in reducing droplets in the air. HVAC systems can also make transmission rates increase due to not having a filter in the system even if it is a low rated MERV filter. As for surface transmission it seems that SARS illnesses survive longer on stainless steel and on plastic. Results show that the viruses can be viable in the air for hours and on surfaces for days. There is a minimum required ventilation rate that is needed to safely dilute the air and remove the dangerous particles that are in the air. Distance also plays into the exposure to nuclei droplets. Droplets in dry air have a smaller nuclei size, while in air with more humidity, the droplet size is greater.

Case Study Interview Findings

In addition to the literature review, a case study was focusing on how Arden's office who specializes in mechanical, electrical, fire protection, and engineering handled the first days of the COVID-19 pandemic as they developed a plan to reopen with their employees returning to work in person. Before the office reopened when the COVID-19 lockdown began in March and April of 2020, Arden shifted to remote work for a few weeks. In order to better understand how Arden Engineering approached their reopening goal, this study conducted interviews with five individuals as illustrated in more detail in the methodology section.

Results of these interviews show that ventilation rates and air filtration were the focuses of combatting COVID in an office setting that were mentioned in the literature review. All participants mentioned ventilation and air filtration in their interviews when asked how the office fought the illness. The four common themes amongst all participants when answering the interview questions were (1) ventilation and filtration, (2) 100% outdoor makeup air, (3) the size/handling capacity of the HVAC system, and (4) monitoring of occupancy. Ventilation and filtration were often mentioned together, so it is combined in a single theme and a discussion section below.

Ventilation and Filtration

Ventilation refers to the movement of air through an environment. Filtration refers to separating one substance from another. All interviewees mentioned that ventilation and filtration were the most important factors in combatting SARS illnesses such as COVID-19. One of the participants when interviewed said:

> *"I think it's important that the proper ventilation is provided to each building, the code required ventilation. If you can do above and beyond that, and install the proper filtration, I think it's definitely the right step. And in fighting the illness, it's definitely going to be helpful."*

Another interviewee when asked how the office responded to the need to upgrade the HVAC system to combat COVID mentioned that

> *"after checking our AHU motors, we determined we could increase our filtration rate by moving up to MERV 13 filters. Once we increased the MERV rating we measured supply and return air movement in each space to determine its air exchange rate which in turn enabled us to determine the occupancy limit."*

Ventilation and filtration typically were used interchangeably as filtration leads to ventilation.

100% Outdoor Makeup Air

Makeup air refers to air that replaces other air that has been removed from a space. 100% outdoor makeup air refers to how air in a space that has been totally removed and is replaced completely by air that comes from the outdoors. One of the interviewees mentioned that bringing in "as much outside air as the system is able to

handle relative to the cooling and heating capacity" is important. One of the downfalls to bringing in more air is "the added outside air or increase in outside air is going to increase your operating costs". According to another interviewee outdoor air "does dilute the contagions in the air, so then we can also exhaust them out and you don't create a recirculation of contaminated air". Further to that point, another interviewee mentioned "air changes and diluting the air as best as possible almost mimicking outdoor environment is of huge importance" to fighting SARS related illnesses such as COVID. When asked, another interviewee mentioned that dilution and 100% outdoor air is "extremely effective." Going further, that same interviewee mentioned that Arden "sacrificed electrical economy in order to run the AHUs 24/7". Furthermore, the interviewee mentioned that they "adjusted the control programs to widen the curve of operation by running 100% makeup air. Doing this dramatically increased our ability to dilute the virus exposure in each space by increasing each room's air exchange rates".

Size and Handling Capacity of HVAC System

HVAC systems are designed based on the size of the building that it is serving and the purpose that the building has. When upgrading a system to meet the needs of controlling SARS illnesses an office such as Arden runs close to 100% outdoor air "your limiting factor being that the sizing of the actual air handlers and the chiller

and boiler system" as one of the interviewees mentioned. When asked about what could be done in the future to help, one of the interviewees mentioned they "would probably consider a different sizing as it relates to ventilation" because if you continue with old units "you are kind of on the threshold of pushing the units to do what they're really not originally designed to do". Another interviewee mentioned that "if we bring in too much fresh air and the system can't handle it will make it a little cooler in the wintertime and a little warmer in the summertime". Furthermore on the challenges with sizing and the handling capacity of the equipment, one of the interviewees mentioned that "A lot of challenges that come with that is the capacity of the equipment to be able to actually even pull moisture out and not bring in too much outside air, where you're actually creating a breeding ground where you have too much relative humidity in the space". High relative humidity, as noted in the literature review, is one of the factors that can lead to the increased spread of SARS-related illnesses like COVID-19.

Monitoring and Controlling of Occupancy

HVAC systems do not always run at full capacity because the occupancy of buildings changes throughout the day. This helps with the longevity of equipment and saves the owner money as it lowers the amount of times certain items need to be replaced and serviced. This is why typically a direct digital control system is used which automatically controls when the system runs and how it runs. To begin with,

before the pandemic began, the system was running “based on how many occupants are in the building as per ASHRAE standard, so much CFM per occupant”. To further explain: “that's how we were operating in the office unless we were in an economizer situation, so we were at a minimum percentage based on occupancy”. When the pandemic began, according to one of the interviewees “the control sequence was probably updated to provide more ventilation here when possible”. Another interviewee mentioned that “all you're doing is increasing your ventilation during occupied timeframes, which essentially could mean additional filter changes”. In contrast another interviewee mentioned that they “were running all the systems 24/7. So even when people weren't here, we were turning the air on” leading to extra wear and tear on the equipment. The monitoring and controlling of occupancy “as part of filtration and air exchange rates, the number of occupants and what they are doing in the space, are a key factor in the equation” of fighting such an illness.

Discussion and Analysis

These results indicate that the major challenges with reopening include: having a system that can handle the increased run time, having the knowledge of what needs to be done to upgrade those systems, understanding occupancy and how that changes through the day, knowing that changes in the upgraded system may affect personal comfort in terms of being too cold or too warm in spots. Also, understanding the impacts of using increased fresh air rates and what impact that has financially and

socially. The strategies to address these were twofold one being to update the system so that it not only conforms to building code, but extends beyond building code requirements and the maintenance of that system whether that be changing out filters when new ones are needed or to change the control system to monitor for occupancy changes and help with the run time of the equipment.

Chapter Five: Conclusion and Recommendations

The objectives of this study were to investigate the relationship between SARS related diseases and ventilation, examine how building design relates to effective HVAC ventilation, and determine what HVAC ventilation techniques are best in reducing the risk of SARS disease related transmission within the indoor environment. In order to accomplish this objective an extensive literature review was conducted as well as interviews with experts involved in the fight against COVID-19 in an office setting. The interviews yielded four common themes of addressing re-opening businesses during a pandemic, particularly COVID-19.

Overall, it is possible to reduce the transmission of airborne diseases using techniques such as moving to 100% outdoor air within a space, but there is no solution to stop transmission in its entirety. All five interviewees agreed that Arden Engineering Constructors, LLC. COVID efforts relating to the upgrade of their own systems can be a model for other offices to safely bring their employees back into the

office environment. It is also clear from the interviews that successful re-openings will involve ventilation and filtration, 100% outdoor air, sizing and handling capacity of the HVAC system, and the monitoring and controlling of occupancy in a space. From the literature review, it seems that there are many different ways that infectious droplet nuclei can travel through the air, and there are many factors that can affect its travel length and path such as relative humidity. A ventilation system design would need to take all of these into account which would be challenging to fully accomplish. This may be the reason why there is not a 100% solution to the problem of airborne transmission. It is also important to note that some of these techniques may be too costly for building owners. Another note may be that the solution to this issue could pose more risks to occupant health.

Some recommendations for future studies may be a study on the building/owner costs of HVAC ventilation techniques that are specifically designed to combat SARS related illnesses. As the world continues to fight the COVID-19 pandemic and tries to understand how we can mitigate transmission, such studies may be instrumental in the implementation of any mitigation innovation. If not used correctly, it is possible that HVAC systems can be making the problem even worse. Further research may be necessary to study how HVAC systems can increase the transmission of SARS related infectious diseases. Due to the pressing matter of COVID-19 transmission, urgent measures to fight this pandemic must be considered. Future research should

look at how different types of offices handled the COVID pandemic including offices that do not have the mechanical knowledge that Arden does have. This could be valuable when determining the optimum way to create a safe environment for employees.

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Appendix A: Interview Questions

- What is your role at Arden engineering?
- What does your day to day life look like here at the office?
- Have you been involved in the COVID fighting efforts in the office?
- How effective do you think HVAC ventilation techniques are in fighting SARS illnesses?
- What upgrades or modifications to the HVAC system have been made in the office to make it safe for employees?
- How effective is dilution in an office? Does the office now run on 100% outdoor air?
- Why and how have co2 levels changed when changing the HVAC system? And how has this been handled?
- What are the differences between the former HVAC system and the modified system?
- Who operates the system and does it need maintenance more often? And is it user friendly?
- What have been the impacts to personal comfort that have been made after upgrading the system?
- Are the modifications that have been done permanent or temporary?

- What have been the financial costs associated with upgrading the system? and also with just modifying the office environment, and also running the new, modified equipment?
- Are there any negative impacts with the upgrading of the system? Does it affect the life of the equipment in any way?
- Have there been any lessons learned with how the office has handled COVID?
- What other COVID mitigation efforts have been done in the office other than the HVAC upgrades?
- Do you think how the office handled COVID could be a model for other offices?
- Are there any other stories that you'd like to share regarding this topic?