ABSTRACT

TAHERI, HELIA. Human-Building Interaction, Thermal Comfort and Indoor Air Quality in K-12 Schools (before and during COVID-19): Suggestions for Stakeholders and Future Studies. (Under the direction of Dr. Traci Rose Rider)

Schools are an important part of children's lives, and school environments have an impact on students' comfort, health, and performance. Thermal comfort and indoor air quality (IAQ) have a noticeable impact on children's comfort, health and learning performance. People feel thermally different in the same condition, and they might have different preferences to interact with their built environment to improve their comfort. COVID-19 added another layer of complexity to these preferences. On the other hand, people are aware of the impact of their built environment on IAQ and their health, and this awareness has been significantly increased since COVID-19 hits the world in March 2020. All leading agencies agreed on the importance of adequate ventilation rate and outdoor air ventilation in safer reopen schools, during the pandemic. Despite the benefits of thermal and IAQ-related recommendations, there might be some drawbacks that make stakeholders not use the suggested strategies or use them ineffectively. This study is an exploratory mixed methods case study that focuses on teachers' preferred behaviors to improve thermal comfort and IAQ in their classrooms, and the benefits and drawbacks of these behaviors. It suggests strategies for different stakeholders to mitigate the drawbacks of those behaviors while enhancing their benefits. The methods used in this study are surveys and interviews. Four elementary schools - a total of 27 survey respondents and eight interviewees - participated in this research. The results of this study show that to improve IAQ teachers prefer to use operable windows and air purifiers and to improve thermal comfort they prefer to use window shading, operable windows, fans, and controllable thermostats. Since different stakeholders play a role in effectively using these building elements, several strategies

were recommended to different stakeholders at the end of this study to mitigate the drawbacks of each behavior while enhancing their benefits. This paper established a holistic and foundational knowledge about stakeholders' role to provide a thermally comfortable classroom with a proper IAQ for students and teachers. Also, due to the limitations of this study and a low number of participants, this paper suggested conducting future interdisciplinary mixed methods research on this subject by expanding the scope and including more stakeholders and schools to have a comprehensive understanding of the classroom conditions and how to improve them with the help of all stakeholders.

Human-Building Interaction, Thermal Comfort and Indoor Air Quality in K-12 Schools (before and during COVID-19): Suggestions for Stakeholders and Future Studies

by
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DEDICATION

I dedicate this dissertation to my mom (Zahra Bagheri), dad (Mozaffar Taheri) and sister (Hilda Taheri) for always being my rocks and cheer leaders, pushing me out of my comfort zone and support me to experience my life the way I love!

BIOGRAPHY

Helia is an ambitious woman who loves to help people have a better life. She has done it from attending volunteering activities to conducting user-centric research to improving people's experience in buildings. Helia is a user-centric, sustainability researcher and an architect, and she is passionate about understanding the interaction between people, places, and the environment. She is an expert in bridging the gap between academia, industry, and community to bring different voices in the research by conducting interdisciplinary human-centered research in architecture firms and research centers. She has eight years of experience working in interdisciplinary teams in industry and academia where she has led, designed, and conducted human-centered research in workplace and K-12 schools.

Helia is a mixed-method researcher and an expert in utilizing qualitative and quantitative methods to decrease individual bias in research, measure changes, and suggest actionable strategies to improve people's and buildings' lives. She can quickly adapt to uncertain changes and situations and make sure that the goal is being achieved on time - defending a Ph.D. during the pandemic says enough for itself. She is an optimistic, flexible, goal-oriented, and multi-thinking team player who turns challenges into opportunities and finds the most efficient configuration to achieve the team and project's goal in the desired timeline.

This dissertation is a step towards Helia's passion to improve occupants' experience in buildings by hearing stakeholders' voices to suggest practical and actionable strategies for them. She is continuously working in industry and academia to utilize, expand and share her knowledge in human-centered research with different audience.

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To get to the place where you feel happy, loved, and successful, you need to have a support system that stays with you strongly, cheers you up, and helps you to move forward with all the difficulties throughout your journey. I would like to sincerely appreciate a couple of special people who make this journey more joyful and successful.

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As an international student, sometimes the journey gets too difficult where you think to give it all up, but I am so lucky to have a wonderful family and friends who supported me to get through the uncertainties.

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Abstract

The COVID-19 pandemic has caused public health and economic crises in many countries including the United States. Among guidelines were published by leading agencies around the world to safer reopen buildings during the pandemic, engineering control strategies are the second effective recommendations only to virus elimination. This paper systematically surveyed and synthesized highly cited architectural guidelines which are utilized in the US and published by leading agencies such as the Center for Disease Control and Prevention, the World Health Organization, and the American Institute of Architects. As reviewed in this paper, all the current architectural strategies agreed on the importance of increasing outdoor air ventilation and maintaining social distancing, which might impact other aspects of buildings and occupants in short-term and long-term. Thus, this paper provides integrated, foundational knowledge for future studies around safer buildings during future pandemics which supports different building stakeholders to make more informed decisions to implement recommendations to positively impact occupants and buildings. Findings suggest conducting more pre/post-occupancy evaluations which include interdisciplinary human-centered studies and building performance analysis using qualitative and quantitative methods to have a more comprehensive understanding about the impact of different strategies on occupants and buildings in light of the pandemic.

Keywords (max 6): Systematic Review, COVID-19, Architectural Guidelines, Occupant Satisfaction, Engineering Control Strategies

Introduction

In early 2020, COVID-19 spread very quickly around the globe (Gupta et al., 2020) and was declared a pandemic by the World Health Organization (WHO) in March of the same year (WHO, 2020a). The COVID-19 pandemic has caused public health and economic crisis in many countries, including the United States (Bauer et al., 2020). The virus has impacted many fundamental aspects of people's lives, such as businesses and education (Chick et al., 2020). It has forced millions of people worldwide and nationwide to work remotely for an extended time (Kniffin et al., 2020). Many scientists around the world, including those at the United States Department of Health & Human Services (USDHHS) and the Center for Disease Control and Prevention (CDC), led intensive efforts to understand better how different groups of people could help to decrease overall exposure and spread of the virus. As such, the CDC has issued several guidelines to reopen workplaces and schools safely during pandemic (CDC, 2021a; 2021b; 2021c; 2021d). The main recommendations for individuals suggested by CDC are (1) to wear masks, (2) to wash hands more frequently, (3) to increase outdoor air ventilation, and (4) to maintain 6-feet social distancing from people who do not live with you (CDC, 2020), which has recently been reduced to 3-feet in K-12 schools (CDC, 2021f). Many people worldwide were hopeful that the virus would be brought under control or disappear sometime soon, but in May 2020, the WHO announced that COVID-19 would be an ongoing issue for the future (BBC, 2020). After this announcement, several health and architecture organizations such as the CDC, WHO, the American Institute of Architecture (AIA), and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) started to issue different sets of guidelines to enable safer reopening for buildings in light of the continued presence of COVID-19.

To better outline practical and feasible strategies for environmental hazard mitigation, the CDC had issued a hierarchy control model to categorize the control strategies - before COVID-19 - into five groups: (1) elimination, (2) substitution, (3) engineering controls, (4) administrative controls, and (5) personal protective equipment (PPE) (Figure 1) (CDC, 2015). As shown in Figure 1, the higher the category of control strategy in the model, the more effective it is to control the hazard. AIA applied this established model to COVID-19, becoming more specific with the outlined control strategies. The modified categories became: (1) elimination, physically removing the pathogen; (2) substitution, not applicable to COVID-19; (3) engineering controls, separating the people and pathogen through architectural and engineering recommendations; (4) administrative controls, instructing people what to do through policy; and (5) personal protective equipment (PPE) instructions such as using masks, gowns, and gloves (Figure 1) (AIA, 2020a). As explained in the Swiss Cheese Model (Reason, 2000), dealing with a hazard involves different human, technology, and natural elements. This model has been applied to pandemic defense by Christakis (2020) and Joon et al. (2020). They state that a single behavior or implementation might not be enough to reduce the spread and the exposure to the virus. Thus, it is important to implement different strategies to reopen buildings more safely during COVID-19 and future pandemics (Sarin et al., 2020).

Considering the effectiveness of engineering control strategies in the hierarchy control models compared to personal and administrative strategies (Figure 1) and given the fact that people spending 90% of their time indoors (Leech et al., 2000), it is important to have a clear understanding about existing architectural and engineering guidelines to provide a safe environment for occupants during the pandemic. Moreover, due to the urgent need of publishing guidelines to safer reopen buildings during the pandemic. almost all published guidelines have mainly focused on maintaining occupants' health in buildings during the pandemic despite the significant role of buildings to improve occupants experience (Olesen, 2005). As a result, the current published reviews on engineering control guidelines have also focused only on occupant's health (Magahed and Ghoneim, 2021; WHO, 2021) while the recommendations might have a broader impact on occupants including their comfort and performance. Given the fact that buildings are responsible for approximately 40% of energy consumption in the US (EIA, 2017), and considering the direct or indirect impact of implementing architectural guidelines on building performance, it is essential to have a more thorough understanding of how recently published architectural recommendations can also incorporate building performance. Thus, the goal of this paper is to build foundational knowledge for future studies around providing safer buildings during pandemics and to bring awareness among different buildings stakeholders - including architects, engineers, facility managers, employers, and administrators - about how to properly and strategically implement each recommendation to improve occupants' health while enhancing occupants' comfort, productivity, and building performance.

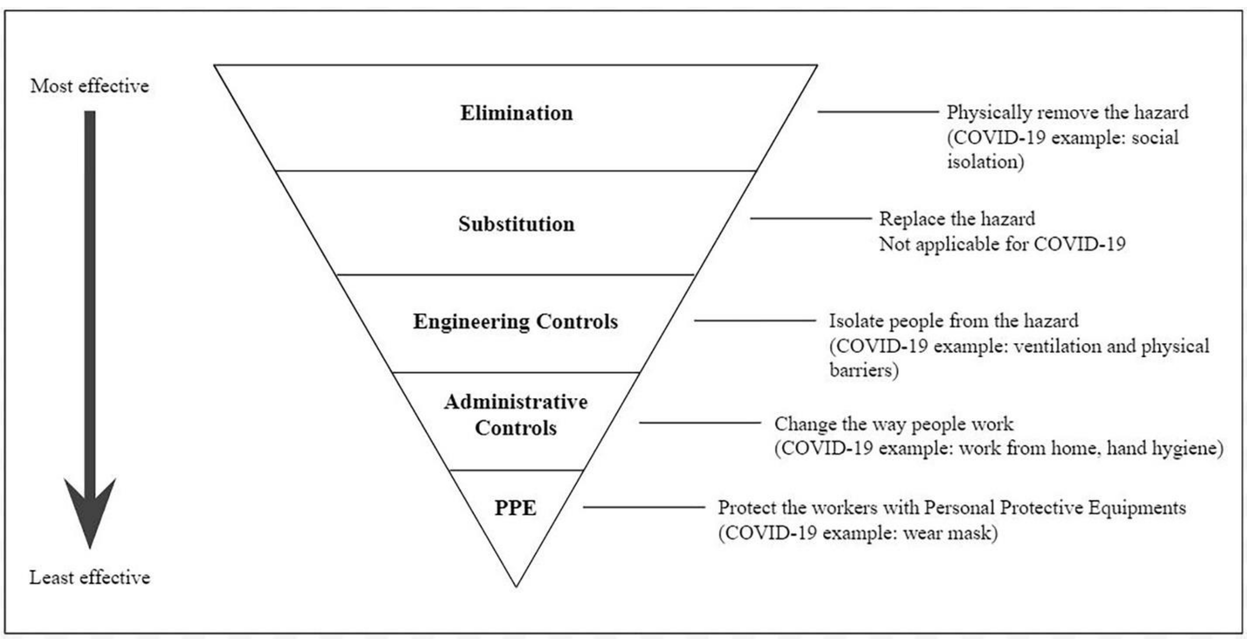

Figure 1.1: Hierarchy of hazard control diagram for COVID-19 (Source: CDC, 2015; AIA, 2020a).

This paper surveys existing guidelines with the focus on architectural strategies to create an overarching understanding of existing engineering control strategies suggested for COVID-19 mitigation. In other words, guidelines which are solely focus on HVAC and mechanical system improvements to provide safer environment for occupants during the pandemic are excluded in this paper, such as ASHRAE guidelines (ASHRAE, 2021a; 2021b). This synthesized information will help build foundational knowledge and identify gaps at this juncture and supports scientific and architectural organizations rethink suggested guidelines to incorporate an approach to meet the needs of occupants and improve buildings performance. Also, increased awareness of how the suggested COVID-19 guidelines would impact occupants' experience and building performance will support more informed design, operational and policy decisions to provide a more comfortable, healthier, and energy-efficient built environment during the pandemic. In a nutshell, the objectives of this paper are: (1) to review CDC, WHO, and AIA guidelines to safely reopen buildings during COVID-19, (2) to synthesize architectural strategies in guidelines published by CDC, WHO, and AIA, (3) to identify limitations and gaps in current architectural strategies around COVID-19, (4) to increase stakeholder awareness about their role and potential impact of their action on occupants and buildings, and (5) to identify opportunities to study the broader impact of architectural strategies on occupants and buildings.

Background

Three leading agencies have released guidelines which include architectural recommendations to safely reopen buildings in light of COVID-19 and are utilized in the United States: CDC, WHO, and AIA. All other guidelines that have been published by different firms and institutes such as U.S. Green Building Council (USGBC) (2020), WELL Building Standard (2020), Gensler Architects (Tranel, 2020), and Perkins&Will (2020) are interpretations of these four foundational guidelines. Each of these three leading agencies has released different documents addressing different building types (Table 1). For example, as shown in Table 1, AIA has published separate guidelines for reopening schools, offices, senior living communities, restaurants, and retail stores. In contrast, WHO and CDC have categorized their documents into only two main building types: schools and offices. Also, WHO (2021) has published a roadmap to improve indoor ventilation in healthcare facilities, residential and non-residential facilities to mitigate the impact of COVID-19. In this roadmap, non-residential facilities include offices, schools, universities, religious and commercial spaces. The engineering control sections of these recommendations include architectural and engineering guidelines, which address both the built environment and mechanical systems. Because of the importance of the built environment in occupant health and satisfaction, this review paper focuses only on existing architectural recommendations published by three agencies - CDC, WHO, and AIA. The main common goals for architectural guidelines suggested by these three main agencies are to increase ventilation rate and outdoor air ventilation and provide a proper layout to decrease the chances of direct and indirect exposure between occupants (CDC, 2021a; 2021b; 2021c; 2021d; 2021e; 2021f; WHO, 2021; AIA, 2020c). Interested audiences may be stakeholders who have a role in properly implementing architectural recommendations, such as architects, administrators, employees, staff, and facility managers of buildings.

As shown in Table 1.1, CDC has provided specific recommendations for schools (CDC, 2020; 2021a; 2021f) and workplaces (CDC, 2020; 2021b; 2021c; 2021e; 2021f). Also, it has created a “quick guide” for teachers to support a healthier classroom environment in light of COVID-19 (CDC, 2021d). The primary recommendations for schools and offices echo those outlined earlier: wear a mask, maintain physical distancing, and provide and maintain adequate outside air ventilation, hand sanitizing, and cleaning protocols. The guidelines for schools and workplaces include all three strategies: personal, administrative, and engineering control. The engineering control recommendations focus to increase ventilation rate and outdoor air ventilation and provide a layout to maintain social distancing to decrease the chance of direct exposure between occupants (CDC, 2021a; 2021b; 2021c; 2021d; 2021e; 2021f). Some of the recommendations in the teacher guide (CDC, 2021d) includes (1) spacing students at least 3 feet apart, (2) turning desks to face the same direction, (3) opening doors or windows, (4) using fans, and (5) posting signs to encourage students to wear masks and wash their hands frequently (CDC, 2021d; 2021f). CDC initially suggested providing physical barriers and maintaining at least six feet of physical distancing in both offices and schools (CDC, 2021b; 2021c; 2021d). In the recent CDC updated guideline for schools, CDC has suggested maintaining at least three feet of physical distancing in classrooms and removed recommendations to provide physical barriers in schools (CDC, 2021a; 2021f). Also, CDC has published research stating that the risk of COVID-19 transmission through surfaces is low compared to direct contact, droplet, and airborne transmission (CDC, 2021g), which shows the importance of providing adequate outdoor air ventilation and maintain social distancing to reduce exposure to virus.

WHO has issued a substantial guideline to more safely reopen workplaces (WHO, 2020b) and a specific checklist for encouraging safety in reopening schools (WHO, 2020c), as well as a roadmap to improving indoor air ventilation in buildings (WHO, 2021). In the guideline addressing workplaces (WHO, 2020b), WHO categorized recommendations into three major groups: (1) general recommendations for daily operations, (2) safer meetings, and (3) safer travel. The architectural strategies in this guideline include opening windows and doors whenever possible during meetings and arranging seats at least 3 feet apart during the meeting if there is space (WHO, 2020b). Overall, most of the recommendations suggested in WHO guidelines are at the personal and administrative level, with a few strategies specifically addressing architectural guidelines to improve the built environment during the pandemic.

Also, WHO published the checklist for safely reopening schools and categorized recommendations into three main groups based on scale (WHO, 2020c): (1) actions at the national level, (2) actions at the local system level, and (3) actions at an individual school level. The audiences for the first two groups of recommendations are policy makers at the national and local levels. The school level category contains the most specific and notable actions with 21 items and has a mixture of architectural, administrative, and personal recommendations for different audiences, including school administrators, architects, staff, parents, and students. Several architectural recommendations in this category include (1) maintain physical distancing, (2) increase ventilation rate and use natural ventilation, and (3) reorganize the school layout to improve physical distancing and hygiene measures (WHO, 2020c). In brief, the school level recommendations in the WHO checklist for schools mainly contain strategies to increase outdoor air ventilation and provide a layout to decrease direct and indirect exposure between occupants.

The WHO offers a roadmap to improve ventilation in health care buildings, non-residential, and residential buildings (WHO, 2021). These sections are further divided into two main groups: (1) natural ventilation and (2) mechanical ventilation. This tool recommends engineering and architectural strategies to improve air ventilation in buildings. Architectural recommendations are mostly suggested in the natural ventilation group of this roadmap. Some architectural strategies include (1) using operable windows, (2) providing cross-ventilation, and (3) enabling stack effect for ventilation. In summary, the main goal of the recommendations of the WHO roadmap is to improve the indoor air quality of buildings during the pandemic.

Focusing on architectural practitioners and the physical environment, the American Institute of Architects (AIA) has published several documents emphasizing engineering and architectural strategies for more safely reopening different types of buildings, including schools, office, multi-family housing, senior living facilities, restaurants, and retail stores (AIA, 2020a; 2020b; 2020d; 2020e; 2020f; 2020g). Each document is dedicated to recommendations for a specific type of building. AIA has categorized spaces in each of these building types and suggested several recommendations at this space-specific level. For example, categories for office buildings include entrance spaces, vestibules, and lobbies, waiting areas, elevators, restrooms, open offices, and break rooms. Some recommendations are (1) providing areas for disinfecting wheelchairs, (2) eliminating coat closets, (3) eliminating seats in the waiting rooms, (4) programming elevators to pick up on only one floor and go to only one floor at a time, (5) maintaining social distancing, and (6) providing touchless fixtures (AIA, 2020b; 2020c). AIA (2020a) clearly states that the audience of these guidelines are mainly architects, employers, building owners, and public officials.

Furthermore, AIA has published an assessment tool for building re-occupancy during the pandemic (AIA, 2020c). This tool covers recommendations specific for a particular type of building or can be implemented in all types of buildings mentioned in the assessment tool. The building types mentioned in this document are schools, offices, multi-family housing, senior living facilities, restaurants, and retail stores. The strategies in this assessment tool are divided into five main categories (AIA, 2020c): (1) elimination, (2) substitution, (3) architectural and engineering controls, (4) administrative controls, and (5) personal protective equipment (PPE). These categories represent the control levels in the hazard control model published by CDC (2015). The architectural and engineering control category is divided into ten groups: (1)

programming, (2) space planning, (3) non-structural partitions and openings, (4) signage, (5) plumbing and plumbing fixtures, (6) mechanical and passive ventilation, (7) electrical, lighting and communications, (8) appliances, equipment, and accessories, (9) finishes and furnishings, and (10) site work. Although there are several overlaps between the architectural recommendations suggested in this assessment tool and the other AIA guidelines, the AIA assessment tool has more detailed recommendations than the AIA guidelines mentioned in the last paragraph. In brief, AIA has a thorough and holistic approach in all the published guidelines and roadmap for suggesting architectural recommendations to increase ventilation rate, provide a layout to decrease the chance of direct exposure between occupants, and provide acoustics treatments and natural lighting.

As shown in Appendix A, CDC focuses only on recommendations to reopen offices and school buildings during pandemics safely, however, AIA and WHO has a border range of building types such as schools, offices, and commercial/retail spaces. There are other building types that either focus on AIA, and WHO. For example, AIA has architectural recommendations for multi-family housing, senior living buildings, and restaurants, and WHO has strategies for residentials, universities, religious, and healthcare facilities. The main common goals in many of the architectural suggestions of all the guidelines are to increase outdoor air ventilation and maintain social distancing (Appendix A). Implementing the architectural recommendations to enhance outdoor air ventilation might have an unintentional or intentional impact on building performance, occupants' comfort, and productivity while improving occupant's health in light of COVID-19. Moreover, since stakeholders play a role in each building type that might be unique and different from other building types, it is essential to have a more comprehensive understanding of the requirements in buildings and policies and action items for stakeholders in each building type to implement architectural recommendations properly. Thus, increasing awareness among stakeholders about the potential impact of their decisions to safely reopen buildings during COVID-19 on building performance, occupants' comfort, and productivity is paramount.

The Review Procedure

Aim

This paper aims to review and synthesize highly cited architectural recommendations from leading organizations which are utilized in the United States to reopen buildings more safely in light of COVID-19. The results of the synthesis process provide a clear and thorough understanding of these strategies. This information helps increase awareness among stakeholders such as architects, engineers, facility managers, employers, and administrators about how implementing these recommendations might impact occupant's health, comfort, productivity, and building performance. It also helps them understand the building, operational and policy requirements to implement each architectural recommendation in different building types properly. This awareness supports them to think systematically and make more informed decisions to decrease the risk of exposure to the virus while enhancing occupant comfort, productivity, and building performance.

Search Methods

This paper mainly focuses on architectural guidelines which are published by leading agencies and utilized in the United States to safely reopen buildings during the pandemic. Guidelines which are solely focus on improvement in HVAC and mechanical systems during the pandemic, such as ASHRAE guidelines, are excluded in this paper. Thus, the reviewed guidelines in this study are published by CDC, WHO, and AIA. CDC and WHO are two national and international organizations which are highly acceptable among scientists and have published guidelines, roadmaps, and checklists to reopen buildings during pandemic safely. Also, AIA is a leading architectural institute based in the United States that includes experts in occupant health and well-being. It has published guidelines and assessment tools for architects to reopen buildings in light of COVID-19 safely.

These three guidelines have been highly cited by well-known organizations and architecture firms such as the U.S. Green Building Council (USGBC) (2020), WELL Building Standard (2020), Gensler Architects (Tranel, 2020), and Perkins&Will (2020). This paper reviewed the primary documents published by these three leading agencies and focused on architectural strategies suggested by them. This review focused mainly on a holistic understanding of each guideline and how it addresses built environment. The recommendations focusing on specific requirements for HVAC operation are excluded in this paper.

Analysis

After thoroughly reviewing the selected guidelines, the architectural strategies have been extracted, categorized, coded, and synthesized from each guideline, and HVAC and mechanical systems strategies have been excluded from the review process (Figure 1.2). Based on the approach of each reviewed strategy and the area of implementation, this paper categorizes these recommendations into four main groups: (1) programming and design, (2) airflow and ventilation, (3) furniture and appliances, and (4) acoustics and lighting. Several subcategories emerged during the analysis and synthesis, as shown in Appendix 1. Each group elaborates separately to have a comprehensive and systematic understanding of current architectural guidelines. Also, this paper establishes a foundational knowledge to increase awareness among building stakeholders about the short-term and long-term impact of these strategies on occupants and environment. This knowledge will support them to make more informed decisions to safely reopen buildings in light of COVID-19, while considering occupants' comfort, productivity, and building performance.

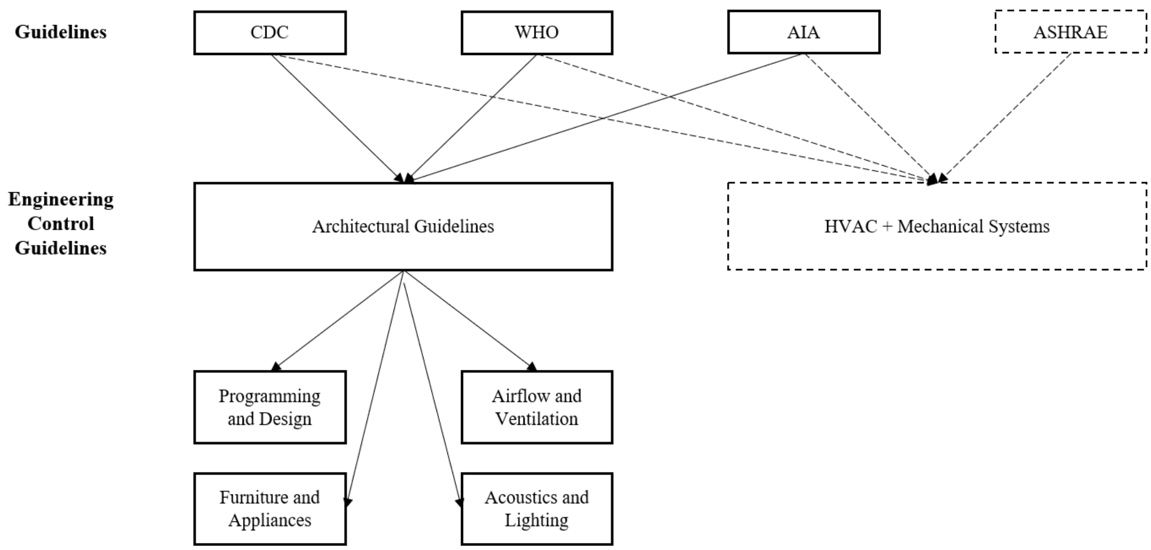

Figure 1.2: The Review Process

Results

As noted previously, themes within the explored guidelines have categorized into four main groups based on their implementation areas: (1) programming and design, (2) airflow and ventilation, (3) furniture and appliances, and (4) acoustics and lighting. The main focus of almost all architectural guidelines published by leading agencies is to increase adequate and clean outdoor air and ventilation rate and provide a layout to maintain physical distancing. In addition, acoustics and lighting group which were suggested by a few guidelines mainly focuses on improving occupants' performance in buildings during the pandemic. This section elaborates each group to better understand the strategies. Please refer to the Appendix 1 for more information about the recommendations.

Programming and Design

The reviewed guidelines include proper design and programming strategies specific to different building types to reopen facilities more safely. The programming and design strategies are divided into two main groups: interior spaces and exterior spaces. Most recommendations in the programming and design category are found in the AIA's reopening assessment tool (AIA, 2020c) or its guidelines for the safe reopening of different specific building types such as schools, office, multifamily housing, senior living facilities, restaurants, and retail stores (AIA, 2020a; 2020b; 2020d; 2020e; 2020f; 2020g). Also, WHO (2020c; 2021), and CDC (2020) suggested a few recommendations for programming and design that are also reviewed.

Interior Spaces

The main goal of programming and design recommendations for interior spaces is to provide a layout to maintain social distancing and decrease the chances of direct exposure between occupants. Based on spaces found in buildings, this paper divides the recommendations specific to interior spaces into five main groups: (1) entrance and lobby areas, (2) elevators, (3) restrooms, (4) Healthcare Facilities, and (5) other spaces such as classrooms, open and private offices (the Appendix B).

Recommendations for entry and lobby areas mostly suggest providing separate entrances and exits (AIA, 2020c; WHO, 2021), touchless entry, sufficient space in the entry to maintain six feet social distancing, one-way direction, and multiple entrances for different groups of people (AIA, 2020c). The suggestions related to elevators are primarily developed for office buildings and include guidelines to limit the number of people in the elevator while providing touchless control (AIA, 2020c). The strategies for restrooms focus on public restrooms and suggest providing physical barriers, toilet lids, and touchless facilities and eliminate doors by providing long entries. Design and programming strategies specific to healthcare facilities suggest reducing the maximum number of people in healthcare spaces and implementing anterooms with double doors or a plastic door zip as a partition in aerosol-generating procedure (AGP) rooms (WHO, 2021). Lastly, recommendations for working and learning areas focus on providing supervised quarantine areas for students, different entrances for classes, and multifunctional spaces for working/learning from home. The recommendations for these spaces also suggest using common areas as larger classrooms, eliminating coat closets and storage, installing a drive-thru and pick-up window for office buildings, restaurants, commercial retails, and providing a designated area visitation in senior living facilities (AIA, 2020c). In brief, decreasing the chance of direct exposure between occupants is the primary goal across all recommendations established for interior spaces.

There is one initial misalignment between the guidelines in terms of maintaining social distancing. While WHO originally suggested keeping three feet physical distancing between students and staff inside and outside of the classroom (2020c), the AIA assessment tool (2020c) and CDC (2021d) suggested six feet distancing. The CDC recently changed its recommendations to align with WHO's the three-foot suggestion (CDC, 2021g).

Exterior Spaces

Published recommendations to maintain a safer exterior environment focus on providing more outdoor spaces for activities, areas for seating, family visits, and working (AIA, 2020c; WHO, 2021). As shown in Appendix 1, suggestions include providing large balconies, patios, gardens, and planting spaces (AIA, 2020c). To encourage and facilitate the utilization of outdoor spaces in less-than-ideal weather, the AIA assessment tool (2020c) recommends providing heating, cooling, and shading facilities for outdoor activities. Also, providing curbside pick-up and using parking lots as waiting areas has been suggested by AIA (2020c) for restaurant operation. On the other hand, it is essential to mention that the lack of knowledge about the importance of outdoor environments as a potential way to increase the risk of exposure to COVID-19 might cause a higher risk of infection by COVID-19 compared to the indoor environments (Senatore et al., 2021). Thus, considering protocols to provide clean outdoor space while maintaining physical distance and wearing masks decreases exposure to the virus in outdoor areas.

Airflow and Ventilation

Another focal point of these recommendations is to increase both airflow and outdoor air ventilation in buildings. The published recommendations primarily suggested two approaches: (1) using operable windows and (2) using fans. All three reviewed guidelines suggested using operable windows to increase fresh air in the interior spaces when the outdoor weather would not negatively impact the indoor condition, and there are no safety issues (i.e., child safety or triggering asthma) (AIA, 2020c; CDC, 2021c; 2021d; WHO, 2021). WHO recommended to use operable windows for 15 minutes upon entering a room, and provide cross-ventilation in buildings instead of having single-sided ventilation and improving the stack effects to increase ventilation (WHO, 2021).

In addition to using operable windows to increase ventilation rate and outdoor air ventilation, WHO and CDC suggested properly using fans to enhance the effectiveness of operable windows (CDC, 2021c; WHO, 2021). Exhausting room air to the outside would help pull fresh air through other open doors and windows (WHO, 2021). Also, CDC (2021c; 2021d) suggested using window child-safe fans in offices and schools, and WHO (2021) recommended to provide a pedestal fan located close to the window and facing toward the window to send interior air out. It is also important to manage the fans in a way that does not blow directly from one person to another (CDC, 2020c; AIA, 2020c). Overall, it is essential to have a clear understanding of how to properly use the fans to increase the ventilation rate and outdoor air ventilation, which helps decrease the risk of exposure to the virus among occupants.

Furniture and Appliances

The focus on furniture and appliances in the context of COVID-19 is to decrease the direct and indirect exposure to possible contamination between occupants in buildings by providing physical barriers, touchless and easy-to-clean appliances and furnishings, and proper furniture layouts that maintain at least six feet of physical distancing (AIA, 2020c; CDC, 2021d; WHO, 2021)Several recommendations suggested to facilitate maintaining six feet social distancing in buildings include decreasing the density or increasing the space of seating in dining or break rooms (AIA, 2020c) and reducing the amount of equipment and furniture to provide more space for occupants (WHO, 2021; AIA, 2020c). The AIA assessment tool (2020c) suggested replacing desk phones with personal headsets, providing extra monitors for video conferencing at workstations, and providing required technologies in the residents' rooms in senior living facilities to support virtual communication.

AIA assessment tool (2020c) and CDC (2021d) also suggest providing physical barriers such as transparent plastics or sneeze guards, particularly in spaces where it is challenging to maintain six feet distance; using cubbies, shelves, and other furniture close to students' and teachers' desks as low barriers (AIA, 2020c); and providing tall booths or temporary partitions in dining areas or large working spaces (AIA, 2020c) (Appendix 1). The updated CDC guideline for schools removed the recommendation to providing physical barriers (CDC, 2021f).

In support of touchless and easy-to-clean furniture and appliances, the AIA assessment tool (2020c) suggests strategies such as providing Bluetooth credit only, touchless, and easy-to-clean vending machines. Other options include utilizing Internet of Things (IoT) technology to control appliances and providing touchless door locks, turnstiles, timecards, restroom facilities, and hygiene stations. Additional strategies for furniture layouts to decrease the direct exposure between occupants in schools include turning desks to face the same direction in classrooms (AIA, 2020c; CDC, 2021d), having students sit on one side of the tables (CDC, 2021d), and providing at least six feet physical distancing between desks and seats (CDC, 2021d; AIA, 2020c). CDC recently published research illustrating that COVID-19 transmission through surfaces is low compared to direct contact, droplet, and airborne transmission (CDC, 2021g); thus, the recommendations for touchless furniture and appliances have a lower priority compared to suggestion to enhance outdoor air ventilation and ventilation rate and maintain physical distancing.

Acoustics and lighting

Wearing masks is the highest recommended individual-level strategy suggested by the CDC to prevent community spread of COVID-19 (CDC, 2020), but it might create barriers during communication (Magee et al., 2020). Masks can impact speech perception, especially in noisy environments or for hearing-impaired listeners (Hampton et al., 2020). Thus, one recommendation is to enhance acoustic treatments to ensure that occupants can both hear and be heard in their conversations in schools, offices, and senior living communities (AIA, 2020b; 2020c; 2020d; 2020e).

Lighting is also identified in these guidelines as an essential factor in buildings, helping to address COVID-19. AIA has suggested providing electrical lighting that simulates daylight to improve mental health in multifamily housing (AIA, 2020f), using natural light as much as possible in school buildings (AIA, 2020d), and utilizing motion control sensors or phone-based applications to control the lights in retail stores (AIA, 2020g). Since occupants spend more time indoors in light of COVID-19, compared to prior to the pandemic, implementing architectural recommendations related to lighting might improve occupants' experience in buildings in light of COVID-19.

Discussion and Synthesis

This paper aims to synthesize existing architectural guidelines published during COVID-19 to help inform the safe reopening of buildings during the pandemic. The guidelines selected for this review and synthesis were the highly used, reliable guidelines published by CDC, WHO, and AIA. Big organizations and architecture firms such as USGBC, WELL Building Standard, Gensler, and Perkins&Will cited these three guidelines, making the reviewed guidelines highly reliable. While all three reviewed guidelines have architectural recommendations for safely reopening schools and offices, AIA, and WHO guidelines have suggestions for a broader building type compared to CDC guidelines. It is essential to mention that CDC and WHO include different strategy levels, including elimination, administrative, engineering control, and PPE recommendations; however, AIA mainly focused on architectural and engineering recommendations to safely reopen buildings (Appendix A).

People spend 90% of their time indoors (Leech et al., 2000), and indoors is where the virus can spread with greater speed. Thus, it is important to have guidelines focused on improving the built environment, especially in light of COVID-19. Moreover, the 90% might increase to 100% for some people in light of COVID-19 (Abouleish, 2021), which further underlines the importance of providing acceptable indoor air quality in support of human health. Since the onset and rapid spread of COVID-19, different groups of people, including scientists, engineers, policy makers, and occupants have become more aware of how significantly indoor air quality can impact health (Megahed and Ghoneim, 2020; Pettit et al., 2018). Thus, people are more willing to implement suggested recommendations focusing on improving their health in reopening buildings during a pandemic. As mentioned, the model outlining a hierarchy of hazard control had been previously issued by CDC (2015) and was quickly applied to COVID-19 by AIA (AIA, 2020a). Among the four layers of this model used for COVID-19 - elimination, engineering controls, administrative controls, and PPE - engineering control strategies are the second most effective group after elimination strategies to safely reopen buildings in light of COVID-19. These strategies include both architectural and engineering recommendations.

This paper categorized architectural recommendations into four groups considering their applications: (1) programming and design, (2) airflow and ventilation, (3) furniture and appliances, and (4) acoustics and lighting (Appendix B). Overall, the main goals for all the categories except for acoustics and lighting group are to increase outdoor air ventilation and ventilation rate (i.e., utilizing operable windows and fans), and decrease the chance of direct or indirect exposure between occupants (i.e., maintaining social distancing, and providing touchless surfaces). The main goal for the acoustics and lighting group is to improve occupants' performance and mental health during the pandemic. Considering the importance of airborne transmission in mitigating the risk of exposure to COVID-19 compared to the surface transmission in recently published report by CDC (CDC, 2021g), strategies which are focusing on increasing air ventilation and maintaining social distancing have higher priorities over the ones with the focus on touchless and sanitized surfaces. Thus, the airflow and ventilation group have the highest priority among all other groups. Also, strategies focusing on outdoor spaces and social distancing mentioned in the programming and design, and furniture and appliances groups are essential to be considered in addition to increasing airflow and ventilation in the spaces.

Despite the importance of architectural recommendations in the airflow and ventilation group which are mainly focused on utilizing operable windows and fans in the space, it might be difficult, expensive and time-consuming to be implemented in many existing buildings due to the space limitations. Also, the buildings might have to be shut down for a couple of days to install proper windows or fans to increase outdoor air ventilation and ventilation rates. Thus, in the absence of operable windows and fans in existing buildings, this paper suggests referring to the mechanical systems strategies (i.e., ASHRAE Guidelines) to increase airflow and ventilation. Also, it is highly encouraged to use architectural strategies mentioned in the airflow and ventilation group to design new buildings or major renovations. On the other hand, strategies in the programming and design, and furniture and appliances groups which focus on maintaining social distancing and providing outdoor spaces, are easier and less time-consuming to implement by designing efficient furniture layouts in existing buildings. These strategies should also be utilized as guidelines to design new buildings and major renovations to provide adequate space to maintain social distancing and space flexibility.

Furthermore, strategies suggested in the airflow and ventilation group to safer reopen buildings have a direct impact on indoor air quality and HVAC loads which might lead to a shift in building energy consumption and occupants' comfort and productivity (Pan et al., 2018; Wargocki et al., 2007; Dias et al. Jul 2011). These impacts are being overlooked in the surveyed guidelines – CDC, WHO, and AIA - and the existing reviews (Megahed and Ghoneim, 2021; WHO, 2021) due to the urgent need to publish strategies to safer reopen buildings in the pandemic and protect economy and livelihood. Thus, this paper suggests researchers, architects and policy makers to consider the short-term and long-term effects of these recommendations on occupants, building performance, and climate change. This systematic approach will support stakeholders make more informed decisions and choose the recommendations wisely and strategically to mitigate the negative and unexpected impacts of the guidelines on occupants and environments in short-term and long-term while providing a healthy environment for occupant in light of the pandemic.

Moreover, using operable windows and fans are two of the most mentioned recommendations by guidelines to increase ventilation rate and outdoor air ventilation (AIA, 2020c; CDC, 2021f; WHO, 2021). Studies show that people with control over their built environment, such as opening/closing windows, can tolerate higher temperature ranges (Brager et al., 2004; Mishra and Ramgopal, 2015; Buonocore et al., 2019; Jindal, 2018) and feel better both mentally and physically (Taylor and Brown, 1988) than those without such control. In this instance, the COVID-19 recommendations nicely align with strategies to increase occupant comfort and satisfaction. However, wearing a mask, which is the CDC's strongest recommendation to stay safe from COVID-19 (CDC, 2020), might impact an individual's perception of their thermal comfort because the heat generated from their breath is trapped close to their face (Penn Medicine, 2020). This primary suggestion does not align with strategies to support human comfort. Given the fact that thermal comfort plays an important role in occupant performance and productivity (Wargocki et al., 2007; Mujan et al., 2019), and considering several suggestions to have operable windows and fans in buildings that increase the occupants control over their built environment, this paper suggests researchers to conduct more studies on the potential shifts in the comfort zone for occupants in light of COVID-19.

Besides, the synthesis of the review guidelines showed that several actions need to be initiated by different groups in both direct and indirect roles to implement each of the recommendations appropriately. To properly initiate each action, it is important to have built environments and policies which support implementing each recommendation. For example, the suggested steps for properly opening windows in schools, which is indicated in all four of reviewed guidelines in this paper, would depend on having: (1) operable windows, (2) a school policy that allows teachers to open windows, when necessary, (3) teachers are willing to open windows, and (4) proper outdoor weather conditions (CDC, 2021d). To establish appropriate implementations for these conditions, different groups of stakeholders should contribute their expertise. These stakeholders would include architects who would consider operable windows in their design; school administrators who provide a proper school policy; facility managers who operate the HVAC system to align with and support operable windows; and teachers who are the ones who open the windows. Thus, this paper calls for more interdisciplinary projects and research which bring all stakeholders around the table to implement the strategies more effectively.

Moreover, considering the different stakeholders', occupants', and buildings' needs in each building type, it is significant to establish a clear path for implementing each strategy for different building types which outlines the required policies, building elements, and participants to successfully implement the suggested strategies and create a transparent process where individuals can understand their role. It also helps stakeholders understand how their participation can lead to a healthier, more comfortable, and energy-efficient environment. Besides, some of the recommendations are most appropriate when designing new buildings, while others might be applicable for existing buildings. For example, most recommendations can be implemented in new and existing buildings, such as providing outdoor space and seating with proper heating, cooling, and shading. On the other hand, several interior or ventilation recommendations, such as providing separate entrances for different groups or using operable windows, could easily be applied to new buildings but would be much more difficult and costly to implement in existing buildings. In brief, more information about the stakeholders and existing conditions are required to properly implement and strategize around each recommendation.

Future Research

Although some reviews of the guidelines have been conducted on published engineering control guidelines to decrease the risk of exposure to the COVID-19 virus for safer reopening buildings, there are still several unanswered questions that are an opportunity for future studies. It is good to mention since stakeholders', occupants' and buildings' needs of each building type might be different from other types of buildings, it is suggested to answer each of the following questions for each building type separately. Some of these unanswered questions are: (1) What is the potential short-term and long-term impacts of each architectural recommendation on occupants' comfort, productivity, and building performance? (2) Has the standard thermal comfort zone shifted in light of COVID-19? (3) What are the required policies and building elements to properly implement each recommendation in existing and new building? and (4) What are the action items for stakeholders to properly implement each recommendation?

Having these questions answered helps stakeholders such as architects, engineers, facility managers, employers, and administrators have a clear understanding of their roles in supporting occupancy health and growing practical knowledge about how each recommendation might be used more effectively. Moreover, it helps increase the knowledge among stakeholders to have a comprehensive understanding of required building elements and policies to properly implement each recommendation in different building types. For example, schools are the second most prevalent environment in children's lives after their homes (Baki-Biro et al., 2012), supporting the importance of school environments in students' learning performance, health, and comfort (Abramson et al., 2006; Madueira et al., 2009; Annesi-Maesano et al., 2013; Mendes et al., 2014;

Ameida et al., 2016). Moreover, children are more vulnerable to environmental conditions compared to adults (Suk et al., 2003; Faustman et al., 2000), and the inadequate ventilation rate in most classrooms (Mendell and Heath, 2005). Thus, it is essential to understand how the current built environment and school policies might support or limit implementing architectural recommendations to safely reopen schools in light of COVID-19.

For future research, this paper suggests conducting more pre/post-occupancy evaluations on different types of buildings to have a holistic understanding about the impact of architectural strategies on occupancy and buildings. This paper encourages researchers to particularly utilize interdisciplinary human-centered approaches in hand with building performance analysis using both qualitative and quantitative methods such as close-ended surveys, interviews, and focus groups with different stakeholders would help establish a better understanding of important topics. Specifically, questions addressing occupants in this area that should be further researched include: (1) How do different occupants perceive their comfort, health, and productivity in buildings in light of COVID-19? (2) How might implementing each recommendation interfere or support occupant comfort, health, and productivity? (3) How do occupants wish to change their built environment to improve their experience in buildings, mainly related to this and future pandemics, and (4) How might policies and current building design support or limit the implementation of each recommendation in different building types? Interviews and focus groups with architects, engineers, facility managers, and administrators would also help provide a better understanding of the perception of their roles and responsibilities in safely reopening buildings in light of COVID-19.

These user-focused methods should be integrated with building-focused strategies, often in the realm of simulation, modeling, and monitoring. Suitable methods for conducting building performance studies, as suggested by Hayat et al. (2019), Ahmad et al. (2016), and Li and Nielsen (2011), include environmental monitoring and building performance simulation in the form of Computational Fluid Dynamics (CFD) and energy/daylight analysis. Computational Fluid Dynamics (CFD) has become one of the most used tools to analyze building performance around ventilation (Li and Nielsen, 2011). Hayat et al. (2019) suggested conducting environmental monitoring to have a realistic understanding of how buildings perform. This monitoring helps establish the impact of implementing each recommendation, or a compilation of suggestions on building performance and environmental condition. Intentional exploration, including these questions and approaches, will help develop a more precise and comprehensive understanding of future guidelines for different sectors. This approach would also support stakeholders' ability to make evidence-based decisions to improve occupant health and comfort, productivity, and building performance in light of COVID-19 and future pandemics.

Conclusion

The COVID-19 pandemic has significantly increased awareness about the critical importance of indoor air quality among different groups of people, including architects, engineers, administrators, and occupants. Several guidelines have been published since the onset of COVID-19 to provide recommendations to support a healthier built environment during the pandemic. Engineering control recommendations - include architectural and mechanical systems strategies - are the second most effective category to provide a healthier built environment during pandemics. Due to the importance of the built environment in people's lives, this paper reviewed, and synthesized existing architectural guidelines published by highly cited and reliable institutes which are utilized in the United States, including CDC, WHO, and AIA. The reviewed strategies are being categorized in four groups based on their applications: (1) programming and design; (2) airflow and ventilation; (3) furniture and appliances; and (4) acoustics and lighting.

Considering the recent results published by CDC (CDC, 2021g) stating the importance of virus airborne transmission compared to the surface transmission, strategies for increasing air ventilation and maintaining social distancing have higher priorities compared to the ones with the focus on touchless and sanitized surfaces. Thus, it is highly recommended to use operable windows and fans and provide proper layout indoor and outdoor to maintain social distancing in spaces to mitigate the risk of exposure to virus. While the utilizing operable windows and fans to improve airflow and ventilation have the highest priority among all other groups, they might be difficult, expensive, and time-consuming to implement in existing buildings. Therefore, in the absence of operable windows and fans in existing buildings, this paper suggests stakeholder to refer to the strategies focused on mechanical systems (i.e., ASHRAE) to increase airflow and ventilation. On the other hand, architectural strategies related to outdoor spaces and maintain social distancing are easier and less time-consuming to apply in the existing buildings. This paper highly encourages stakeholders to consider implementing these strategies in existing buildings, while it is also importance to consider them to design adequate indoor and outdoor spaces in new buildings to maintain social distancing for different activities.

Moreover, since all architectural guidelines have emphasized on the importance of increasing outdoor air ventilation and ventilation rate, implementing many of these guidelines might directly or indirectly impact occupants and building performance. However, due to the urgent need to publish guidelines to encourage safer reopening of buildings during COVD-19, current guidelines (CDC, WHO and AIA) and the reviews conducted by Megahed and Ghoneim (2021) and WHO (2021) mainly focus on improving occupant health in buildings. Due to the impact of the built environment on occupant health, comfort, and productivity (Olesen, 2005), and given the fact that buildings are responsible for 40% of energy consumption in the US (EIA, 2017), it is important to be more aware of how these architectural recommendations in different building types can also intentionally or unintentionally incorporate occupant comfort, productivity, and building performance while improving occupants' health. Also, to properly implement each of the given suggestions, it is essential to clearly understand different stakeholders, specific action items, and required building elements and policies that would support properly implementing recommendations in new or existing buildings.

This paper suggests mixed methods pre/post occupancy evaluation for future research to have a better understanding about the following:

1- Occupants' perception of their comfort, health, and productivity in buildings in light of COVID-19.
2- The short-term and long-term impacts of current architectural guidelines on occupants' comfort, health and productivity and building performance.
3- Occupants desired interactions with their built environment to improve their experience in buildings, mainly related to this and future pandemics.
4- If current policies and building design support or limit the implementation of each recommendation in different building types.

This paper suggested to utilize both human-centered studies and building performance analysis to answer these questions for different building types, including schools, offices, commercial and residential buildings. Also, it is suggested to include all stakeholders to conduct future studies to have a better understanding about their needs and also increase their awareness about the importance of their role improve occupants experience and building performance. To provide a deeper understanding of the published recommendations and improve future iterations of these guidelines, this paper suggests utilizing both qualitative and quantitative methods including surveys, interviews, focus groups, environmental monitoring, CFD and energy/daylight analysis. Using these methods will help establish evidence to better understand the comprehensive impact of health-oriented recommendations as suggested by existing guidelines that can include other aspects of occupants and buildings and improve future guidelines in upcoming iterations.

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2. CHAPTER 2: Benefits and Drawbacks of Teachers' Behaviors to Improve Indoor Air Quality in Elementary Schools in the United States: Suggestions for Stakeholders and Future Studies

Abstract

During the initial onset of the COVID-19 pandemic, a number of leading agencies in health and design agreed that adequate ventilation rates and outdoor air circulation were important in safely reopening schools. These agencies suggested using operable windows and air filtration to provide clean and sufficient outdoor air for classrooms, improving indoor air quality (IAQ) and supporting increased student learning performance. Despite the benefits of these suggestions, certain drawbacks might prevent stakeholders from appropriately engaging in the recommendations. This paper shares an exploratory mixed method case study focusing on teachers' preferred behaviors to improve IAQ in classrooms before and during the pandemic, while addressing perceived pros and cons. Surveys and interviews with teachers and facility managers provide the data for analysis. Four elementary schools in the United States participated in this research resulting in 27 survey responses and eight interviews. Results indicate that teachers prefer to open/close windows and utilize air purifiers to improve classroom IAQ. However, the results also show that different identified IAQ-related behaviors have pros and cons, which may prevent teachers from using these strategies effectively; thus, this paper suggests recommendations for different stakeholders to effectively utilize operable windows and air purifiers in schools.

Keywords: Elementary Schools, Indoor Air Quality, Teacher Behavior, Benefits and Drawbacks, Suggestions, Different Stakeholders

Introduction

Schools are the second most formative space in children's lives after their homes (Baki-Biro et al., 2012; Mendell et al., 2013), illustrating the importance of the school environment on student learning performance, health, and comfort (Abramson et al., 2006; Annesi-Maesano et al., 2013; Almeida et al., 2016). Indoor air quality (IAQ) and school ventilation rates are important parameters impacting student health and learning performance (Wargocki and Wyon, 2007; Daisey et al., 2003 Haverinen-Shaughnessy et al., 2011). People have become increasingly aware of the impact of IAQ on their health over the last two decades (Mendell and Heath, 2005), with this awareness notably growing since early 2020 when COVID-19 spread quickly worldwide (Gupta et al., 2020). A respiratory virus transmitted through droplets and direct contact with an infected person (CDC, 2021a), the World Health Organization (WHO) declared COVID-19 a pandemic and an ongoing issue in early 2020 (WHO, 2020a; BBC, 2020). This virus quickly impacted fundamental aspects of people's lives, such as education and businesses worldwide (Chick et al., 2020), by requiring remote working and learning. COVID-19 shut down schools around the globe. In April 2020, over 1.2 billion students globally had experienced online learning (Li and Lalani, 2020).

Unfortunately, based on a national survey in the United States, 32% of parents are unable to work remotely, and 55% prefer in-person schools for their children even during the ongoing COVID-19 pandemic (Kiernan, 2020). Schools are integral to many countries' economies and students' futures (Kiernan, 2020; Kniffin et al., 2021). It is essential to allow schools to safely remain open during COVID-19 and future pandemics to protect economies, support working parents, and support children's development while protecting livelihoods. Several leading agencies such as the Center for Disease Control and Prevention (CDC), WHO, the American

Institute of Architecture (AIA), and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) published guidelines to safely reopen buildings in the United States early during the pandemic. These guidelines aim to mitigate the risk of occupants' exposure to the virus through air and surfaces. CDC has also published research reporting that the risk of COVID-19 transmission through surfaces is low compared to direct contact, droplet, and airborne transmission (CDC, 2021b), highlighting the importance of adequate outdoor air ventilation and clean air in interior spaces.

According to the CDC, as of January 5, 2022, 62.3% of Americans (approximately 207 million) have been fully vaccinated (CDC, 2022). Unfortunately, new variants of COVID-19 (i.e., Delta and Omicron) which have higher contingency are rapidly and continuously arriving, and CDC reported that the effectiveness of existing COVID-19 vaccines on new variants is unknown (CDC, 2021f). Considering the importance of schools in children's development and the larger economy, it is essential to continue to provide a healthy environment. Students and teachers must be able to safely learn and socialize during this and future pandemics, regardless of vaccination rates.

Published guidelines suggest using operable windows and improving HVAC air filtration and ventilation systems to improve IAQ in classrooms to help mitigate virus exposure (CDC, 2021c; WHO, 2020b; AIA, 2020; ASHRAE, 2021). Also, having adequate ventilation rates help keep classroom environments comfortable while improving student learning performance and outcomes (Gao et al., 2014; Wargocki and Wyon, 2007; Satish et al., 2012). Unfortunately, previous studies indicate that many classrooms have inadequate ventilation rates for children, even prior to pandemic concerns (Mendell et al., 2013; Haverinen-Shaughnessy et al., 2011; Mendell and Heath 2005; Daisey et al., 2003). Thus, it is essential to understand how to improve ventilation rates in schools to continue to provide a comfortable and healthy environment for students and teachers, especially during the current and future pandemics.

However, to effectively implement strategies to improve IAQ, it is essential to have policies in support of those strategies. For example, as CDC states, to properly use operable windows to improve IAQ in schools during COVID-19, it is essential to have (1) operable windows in the classrooms, (2) school policies supporting the use of operable windows, (3) teachers willing to open windows, and (4) suitable outdoor weather (CDC, 2021e). Thus, several stakeholders and conditions such as architects, school administration, teachers, and outdoor weather all play a role in efficiently using operable windows to improve IAQ.

Although operable windows and air filtration have undeniable benefits for improving IAQ, potential drawbacks include outdoor dust, pollen, and noise (Goins et al., 2012), which discourage users. There is a lack of research addressing benefits and drawbacks of operable windows and air filtration; additional studies are essential to have a comprehensive understanding of how to mitigate potential disadvantages to support teachers in using these strategies effectively. This study focuses on teachers' preferred behaviors to improve IAQ in their classrooms, the associated pros and cons of these behaviors and strategies, and how to enhance benefits of the strategies while mitigating drawbacks. Furthermore, since several stakeholders impact these behaviors in schools, this study provides suggestions for different stakeholders to improve IAQ in classrooms.

The objectives of this paper are to (1) identify teachers' preferred behaviors to improve classroom IAQ in elementary schools, (2) understand teachers' decision-making factors to initiate those behaviors, (3) elaborate on drawbacks and benefits of the most common teacher behaviors to improve IAQ, and (4) suggest strategies to various stakeholders to support IAQ-related behaviors in schools. The research questions are: (1) How have teachers interacted with their classrooms to improve IAQ in K-12 schools before and during COVID-19? And (2) What are the benefits and drawbacks of using operable windows, fans, and air purifiers to improve classroom IAQ?

Methods

This paper is a part of a Ph.D. dissertation studying human-building interactions, thermal comfort, and IAQ in K-12 schools in the United States. This paper focuses on IAQ-related behaviors, benefits, and drawbacks, and establishing suggestions for different stakeholders to mitigate disadvantages while enhancing benefits of IAQ-related behaviors. This study includes surveys and interviews with teachers and school facility engineers.

Case Study

A purposeful sample of schools participated in this study (Table 2.1), designated by letters to maintain anonymity. These schools were chosen because of personal connections with school principals and architects, which facilitated agreements to conduct the study during COVID-19 after IRB approval. Surveys and interviews with teachers, and facility engineers were conducted between March - September 2021.

Survey

An online, anonymous survey with closed-ended and open-ended questions was created in Qualtrics; school administration shared the survey link with teachers of the four schools. Since school administrators agreed to participate in this research at different times given the stresses of COVID-19, survey responses from the four schools were collected between March-August 2021.

Table 2.1: Properties of schools in this study

School	City	Year built	Grades	Student #	Operable Window	Shading	Fan	Thermostat.
School A	Raleigh, NC	2019	PreK-5	425	No	Horizontal Blinds	No	No
School B	Raleigh, NC	2011	PreK-5	590	Yes	Horizontal Blinds	No	No
School C	Durham, NC	1949, 1955, 1995, 2010	K-5	489	Yes	Horizontal Blinds	Yes (Box Fan)	No
School D	Joliet, IL	2018	PreK-8	427	Yes	Shade Screen	No	No

Several reminders were sent to principals throughout the data collection window, requesting reminders be sent to teachers. Participants could access the questions if they agreed to the consent provided at the beginning of the survey. At the end of the survey, participants were given the opportunity to provide their email to be entered into a raffle to win one of six Amazon Gift Cards per school. Participants were also asked if they were willing to engage in a follow-up online interview. The questions addressing the raffle and interview were asked in a separate survey at the end of the main questionnaire to maintain the anonymity and confidentiality of the survey data. A randomization program selected six teachers at each school to receive Amazon Gift Cards for their participation.

The survey was pilot tested with a local teacher. An elementary teacher recorded herself while responding to a survey draft. She was asked to record her thoughts and perceptions while reading the questions. After reviewing the recording, the questions were revised and shared with the principals of the four schools. With only 27 respondents, the response rates for the survey were lower than expected due to the pandemic and is one of the limitations of this study.

Interview

Online interviews were scheduled and conducted as soon as survey participants expressed interest in a follow-up interview. A total of eight participants agreed to interviews. Participants are designated P#1 to P#8 to maintain confidentiality and anonymity. P#1 through P#6 are teachers, and P#7 and P#8 are engineers in charge of HVAC systems. While teachers indicated their willingness to attend a follow-up online interview at the end of the survey, the two engineers were invited to the interviews through researcher team connections. A variety of teachers participated: Pre-K, second grade, fourth grade, Physical Education, Special Education, and Music. The interviews were recorded after receiving participant consent. Interviewees could turn off their cameras or change their names to maintain the anonymity of their data. Each teacher who participated in the interview received a $30 Amazon Gift Card. These discussions focused on a deeper exploration of survey questions and responses.

Analysis

This study primarily focuses on a quantitative descriptive analysis supported by qualitative data analysis. This mixed methods strategy helps clarify reasons behind teachers' preferred behaviors to improve IAQ and their understanding of benefits and drawbacks, while allowing for strategies to emerge for different stakeholder groups to mitigate the adverse effects of those behaviors.

Quantitative Analysis

Quantitative Analysis

Due to the low number of survey respondents, a descriptive analysis was conducted for the close-ended survey questions. This study uses pandas library v. 1.2.4 (Python Analysis Library) to perform data cleaning, descriptive analysis, and plots.

Qualitative Analysis

The qualitative data were coded and analyzed in Dedoose Desktop v. 9.0.17 and Microsoft Excel. These data include open-ended survey responses and interview conversations. Qualitative analysis in this study consists of the following steps (Figures 2.1 and 2.2.)

1- Interview transcription: The researcher transcribed interviews and removed participant names. All open-ended survey questions were exported into an Excel spreadsheet to further code.

2- Review interviews: Open-ended survey responses and interview transcriptions were reviewed to identify initial emergent codes.

3- Code Generation (Phase #1): The qualitative data was coded with the initial codes that emerged in the previous step.

4- Code Revision (Phase #2): Codes were revised, merged, or divided as appropriate after coding all qualitative data to understand and establish any new trends found in the data.

5- Qualitative Analysis: Qualitative data and emergent codes supported the descriptive analysis and suggested future research.

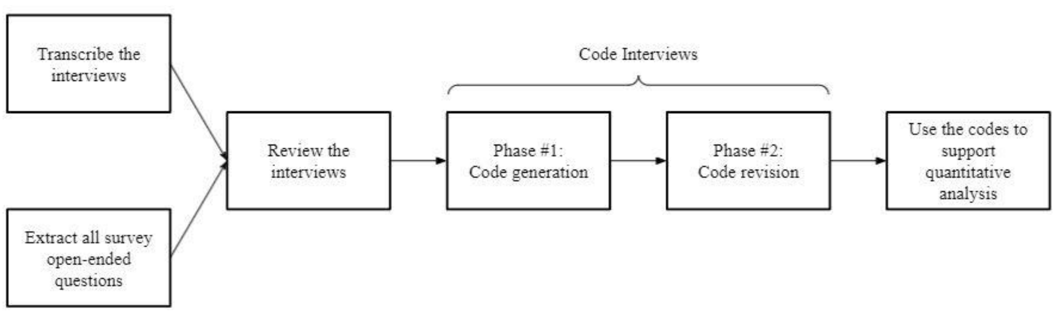

Figure 2.1: Qualitative coding and analysis process

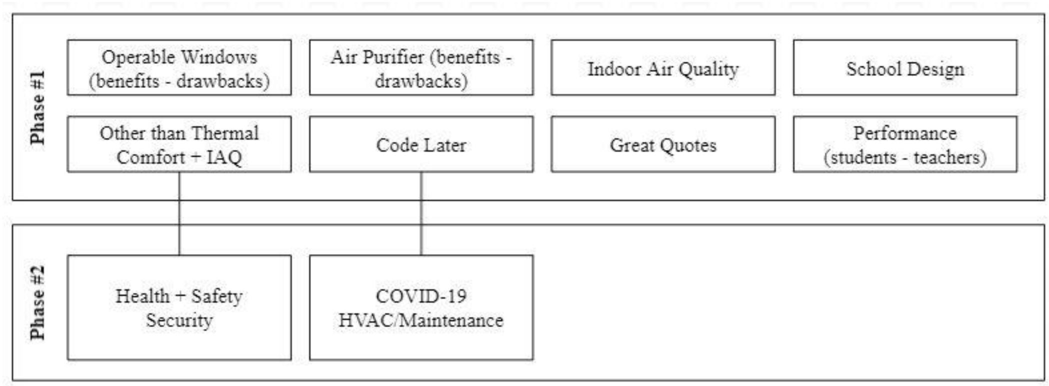

Figure 2.2: Qualitative codes

Results

Participant Demographics

In this section the demographics of 27 survey respondents and eight interviewees participated in this study will be discussed.

Survey Participants

Among the 27 survey respondents, Schools A and D had the most participants (33.3% each), followed by School C (22.2%) and School B (11.1%) (Figure 2.3). Most of the participants were women (66.6%), and most were between the ages of 46-55 (37%), followed by 36-45 (22%), 26-35 (22%), 56-65 (15%) and 18-25 (4%).

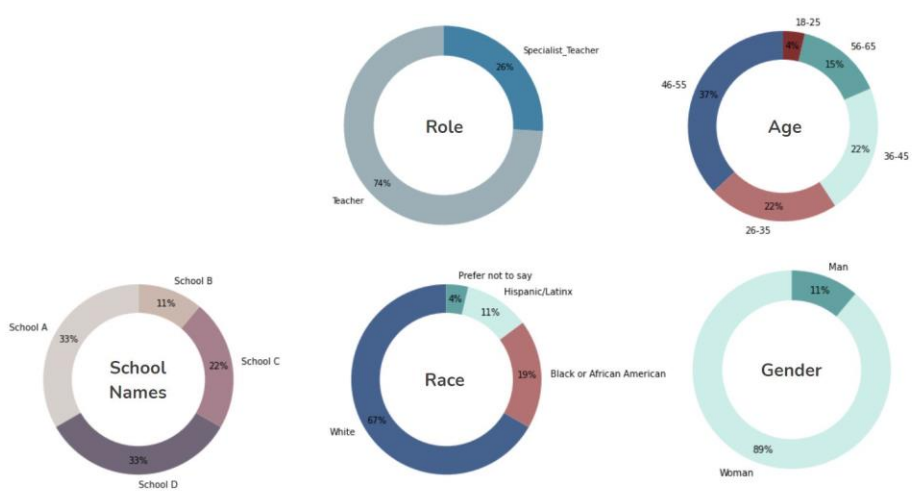

Figure 2.3: Survey participant demographics

Interview Participants

Table 2.2 shows more detail about the interviewees and the properties of their schools. Three teachers worked at School A, one teacher at School B, one teacher at School C, one teacher at School D, and two engineers in the school district of School C.

Table 2.2: Interviewee's characteristics and their schools

Participants	Schools	Experience	Operable Windows	Fans	Shading	Controllable Thermostat
P#1	A	13 years	No	No	Horizontal Blinds	No
P#2	A	16 years	No (a door to the outside)	No	Horizontal Blinds	No
P#3	A	20 years	No	No	Horizontal Blinds	No
P#4	B	2 years	No (a door to the outside)	No	Horizontal Blinds	No
P#5	C	25 years	Yes (horizontal sliding)	Yes	Horizontal Blinds	No
P#6	D	14 years	Yes (vertical sliding)	No	Shade Screen	No
P#7	Project manager (P#7) and energy engineer (P#8) in the School C district.					
P#8						

Indoor Air Quality in Classrooms

In this section teachers' perception of IAQ in their classrooms and their preferred behaviors to improve IAQ will be discussed. The results are emerged from survey and interview data.

Teacher Perceptions of IAQ in Classrooms

The results show (**Error! Reference source not found.**) that 59% of teachers believe t hat classroom IAQ was excellent or good before COVID-19 (26% Excellent; 33% Good); this number decreased to 45% during COVID-19 (19% Excellent; 26% Good). This decrease would be likely because more participants responded “Not Applicable” for their perception of IAQ during COVID-19 than before. Teachers in interviews were asked to rate the IAQ in their classroom on a scale of 1 to 7 (1 the worst and 7 the best) before and during the pandemic. Results of these two types of data show that teacher perception of IAQ in their classrooms is almost the same before and during the pandemic. Also, nearly all teachers emphasized the importance of having fresh and odorless air to have an excellent IAQ in their classrooms.

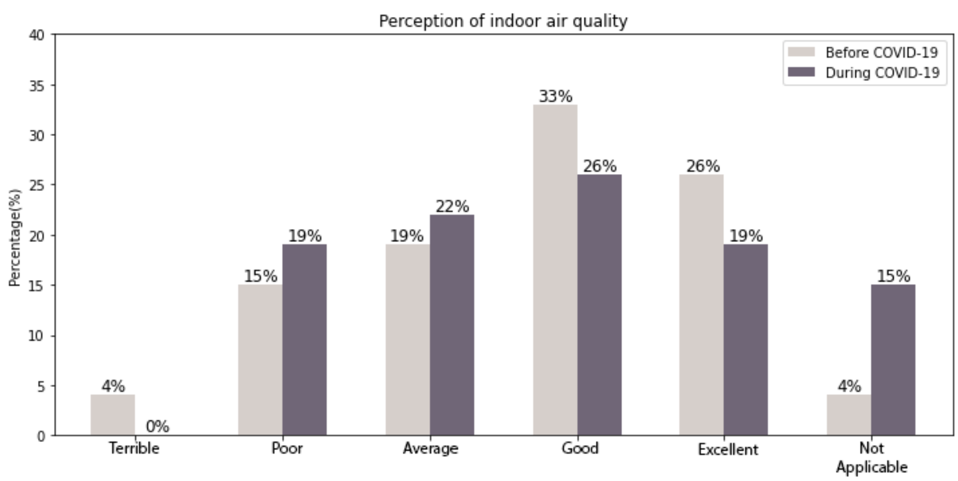

Figure 2.4: Teachers’ perception of IAQ in their classrooms before and during COVID-19

The following quotes are examples of teacher perceptions of IAQ in their classrooms before and during COVID-19:

- P#1: “I'd probably give [IAQ] a six. I think it's pretty good. [Having] a flow of fresh air would be [nice], but other than that, it's not too hot, it’s not too cold, it's not too stuffy, or anything … The only thing that I think would make it perfect… will be some type of breeze of fresh air ... I would give it the six [before and during COVID-19] ...”

- P#4: *“... I would say [IAQ during COVID-19] was about a five because I don't have those operable windows, so if there's some type of smell in my room, it's not going to get out as fast ... and there's no ventilation for the air to go in and out as fast, or there's no fan. So, it's kind of at a five because it's almost like water. Like a lake. If it’s just sitting, there and it’s still...”*
- *P#5: “... I think [IAQ is] about a four, or it was a four. I know they replaced all the filters when we came back to the building in March [2021]. So, it may be a little bit better now ... but it wasn't a huge thing beforehand to replace filters...”*
- *P#6: “... It's a happy place to come every single day because it is fresh and clean, and we don't smell garbage … So, it's just a new start for a lot of people.”*

Actions to Improve IAQ in Classrooms

This section discusses the results from survey and interview questions asking teachers about their preferred interactions with their classrooms to improve IAQ (Figure 2.5). Figure 2.6 also illustrates survey data (on the right) and a selection of codes generated from qualitative data (on the left), which address other behaviors to improve IAQ in classrooms.

Fifty-two percent of surveyed teachers preferred to open/close windows to improve indoor air quality in their classrooms before and during the pandemic (Figure 2.5). In the open-ended survey questions, many teachers indicated that they prefer air purifiers in their classrooms (26%) to improve IAQ. Some also prefer to improve cleaning practices and changing HVAC filters (Figure 2.6). Also, interview responses indicate that teachers sometimes like to have fans to circulate the air in the classroom, which they feel improves IAQ and supports feeling safe during COVID-19 (Figure 2.6). In contrast, air circulation primarily leads to an increase in air flow and feeling more thermally comfortable, which is not a parameter of IAQ. Thus, the fans are used primarily to improve thermal comfort in classrooms, which is not the focus of this paper. Moreover, some interviewees mentioned an increased demand for outdoor spaces for school activities, especially during the pandemic, to provide healthier learning environments for students and teachers. Although outdoor spaces are not the focus of this study, it is essential to understand their importance in providing a healthy environment for students and teachers.

Data indicates that the frequency of using operable windows has increased during the pandemic to bring more fresh air to spaces and improve IAQ in the classroom during COVID-19 (Figure 2.7). Forty-four percent of participants with operable windows used them before COVID-19, with this number increasing to 56% during COVID-19. Also, thirty-one percent of participant chose “Not Applicable” in their responses for during COVID-19 which is likely shows that they weren’t at school during COVID-19.

Teachers were asked what they would do to improve IAQ in their classrooms if they had all the possible options available. Responses show that all teachers would open windows first to improve IAQ in their classrooms if given that opportunity. Two participants shared:

- P#2: *“... The windows, I think during COVID, when we wanted fresh air coming in and out, and we wanted air circulating…. So, I would have felt a lot safer teaching, knowing that there was airflow and air circulation in my space ...”*
- P#5: *“...I open the windows, both of them, and probably have the fan blowing, just to get air moving, so [we aren’t] just sitting in stale air...”*

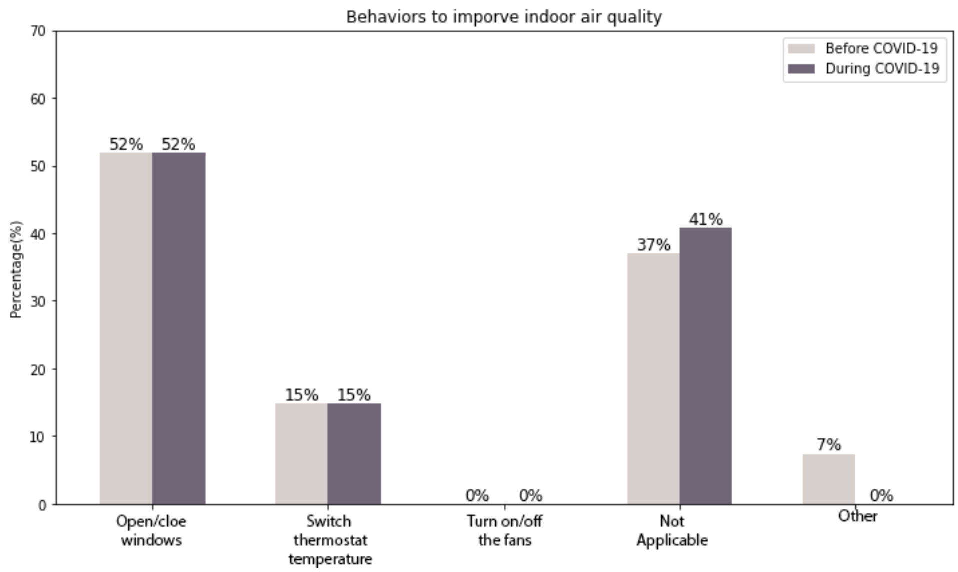

Figure 2.5: Close-ended survey questions: Teachers' preferred behaviors to improve IAQ

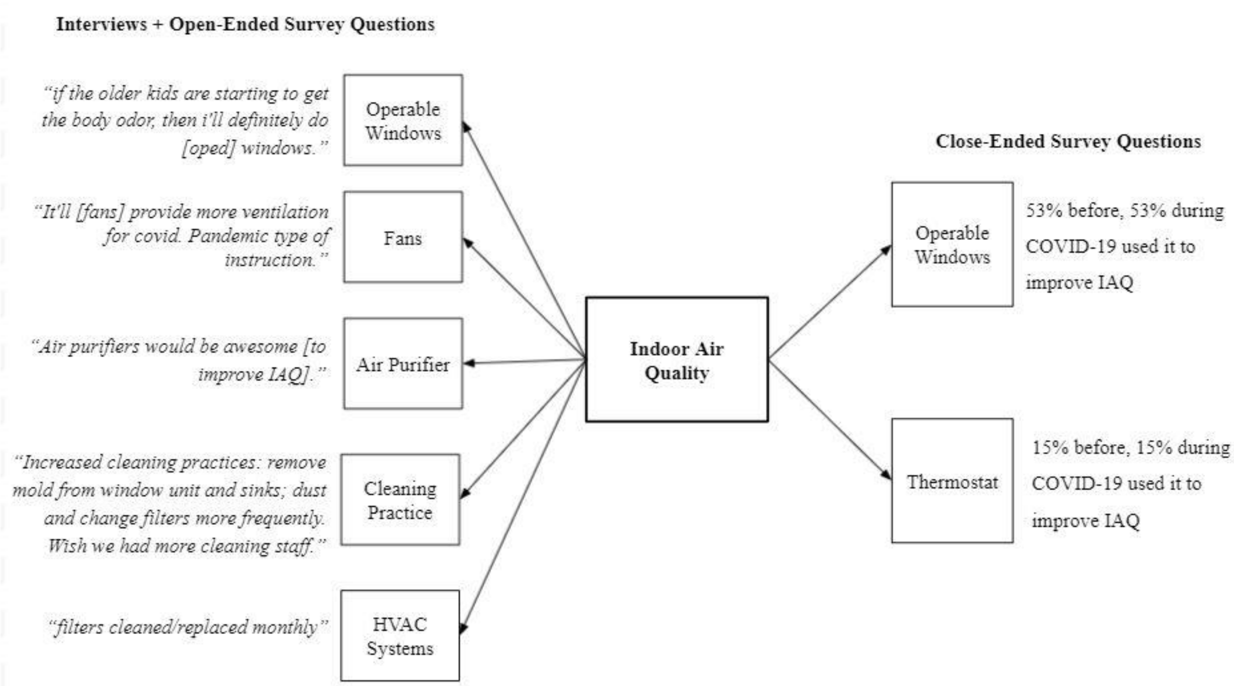

Figure 2.6: Open-ended survey and interview questions: Teachers' behaviors to improve IAQ

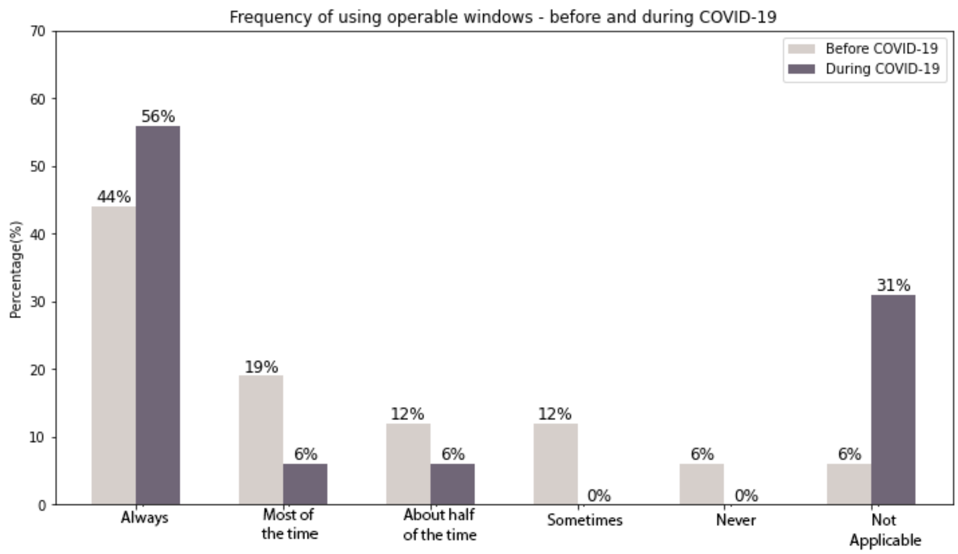

Figure 2.7: The frequency of using operable windows before and during COVID-19

Benefits and Drawbacks of Building Elements

Since most teachers would prefer to use operable windows and air purifiers to improve IAQ in their classrooms, especially during COVID-19, participants were asked about the benefits and challenges of these elements. The surveys and interviews provide data for the results discussed in this section.

Operable Windows

Results indicate that teachers used operable windows to improve a number of conditions before the onset of COVID-19: thermal comfort (75%), IAQ (69%), connection to nature (69%), and student learning performance (31%) (Figure 2.8). However, during COVID-19, concerns of IAQ were most prevalent. The results show that most teachers used operable windows to improve IAQ (75%), followed by improving thermal comfort (50%), connection to nature (44%), decreasing the risk of exposure to COVID-19 (50%), and increasing student learning performance (25%). It is good to mention that all teachers who chose "decrease exposure to COVID-19" also think that opening windows would improve IAQ during COVID-19, while reverse scenario is not the case. This different is something to be considered and investigated in future research. Also, teachers who do not have operable windows indicates that they would use them if they were available in their classrooms (Figure 2.9). The results show that teachers are equally interested in using operable windows to improve IAQ (55%), thermal comfort (55%), and connection to nature (55%), followed by a focus on decreasing the risk of exposure to COVID-19 (45%) and increasing student learning performance (20%).

Most teachers with operable windows believe that operable windows may negatively impact student performance due to outside noise (56%), thermal comfort (56%), and humidity (50%), followed by increasing allergy symptoms due to outdoor pollution/pollen (38%) and decreasing IAQ because of outdoor pollution (12%) (Figure 2.10). The results indicate that most teachers without operable windows think that open windows may increase allergy symptoms (45%), followed by negatively impacting IAQ due to outdoor pollution (36%), thermal comfort (36%), humidity (36%), and student performance due to outside noise (27%).

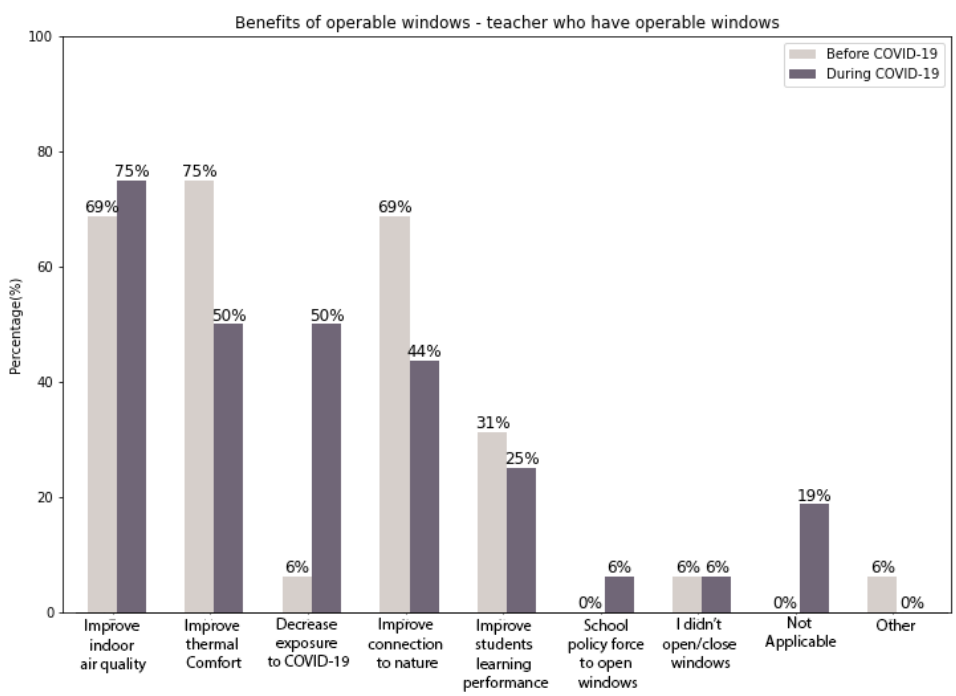

Figure 2.8: Benefits of operable windows - teachers with operable windows

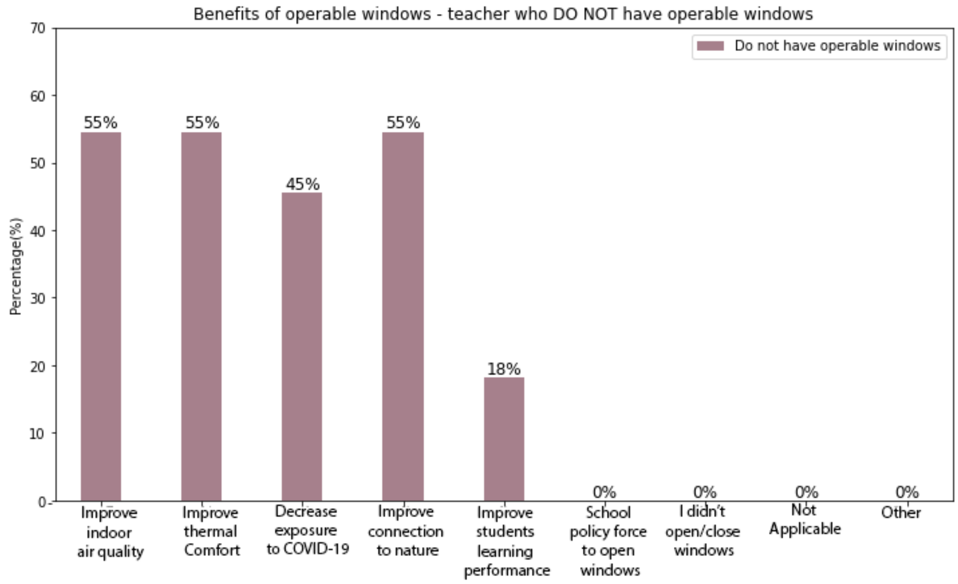

Figure 2.9: Benefits of operable windows - teachers without operable windows

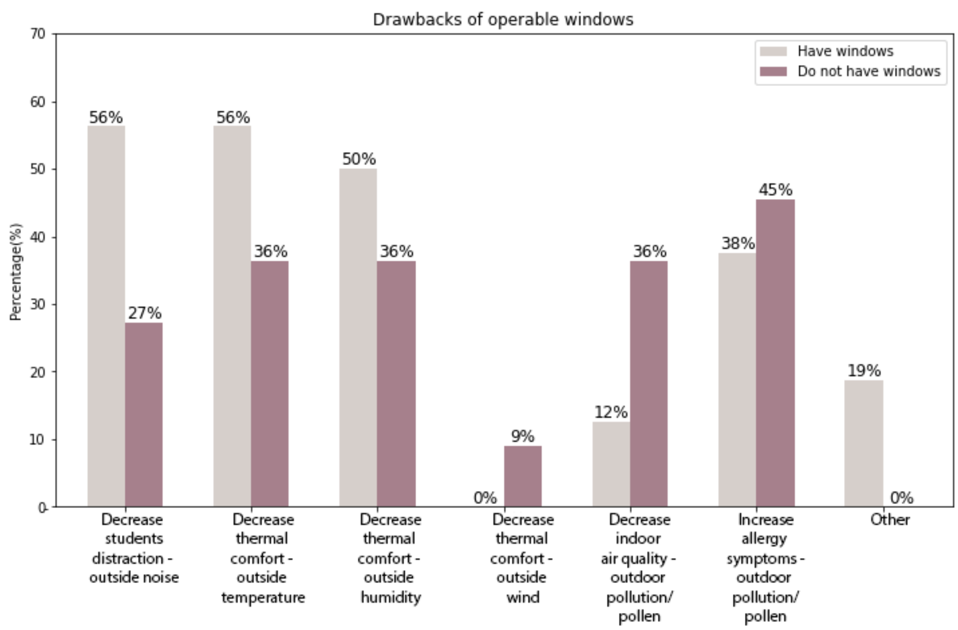

Figure 2.10: Perceived drawbacks of operable windows

Below is an overview of survey and interview responses addressing the benefits and drawbacks of operable windows in classrooms from teachers' and engineers' perspectives. Only one or two examples are provided for each category; themes are based on participants' responses. The results are similar to the results from close-ended survey questions discussed previously. Findings show that all interviewees (teachers and engineers) mentioned the importance of operable windows in improving IAQ in classrooms. After IAQ, most teachers said the benefits of operable windows are to improve thermal comfort, followed by improving health and safety, connection to nature, and student performance. Also, interview results indicate that both engineers that were interviewed think that operable windows might negatively impact HVAC performance, increasing energy use and financial and environmental issues. Several teachers also believe that operable windows might negatively impact security, health, and safety, IAQ, and student performance, in addition to giving access to animals and bugs to crawl into classrooms. Quotes from the interviews for both benefits and drawbacks are sampled below.

Benefits:

- Indoor Air Quality:

  P#1: *"...I love fresh air, especially if you have a weird odor. One time a kid left milk in their cubby, and it was spoiled, and he didn't know it was there, and so they brought in this giant industrial fan to blow it out. If you just open that door or that window, you [remove the odor] very quickly…."*

  P#4: *"... I wish that I had the windows in some respects because it would definitely affect the ventilation …. it's like a student passing gas or something which has happened many times in my room ... then we can all smell that in the room. So, I have no way of truly trying to get that out and moving on..."*

- Thermal Comfort:

  P#4: *"... I use [operable windows] in the summertime mostly. Just because it will be hot in school …."*

P#5: *"... as far as comfort goes, because we do have air conditioning and heat, but sometimes depending on when the school district decides to turn on the AC for us, it would be nice to be able to open more windows, just to have air moving just to cool off the room…."*

- Health and Safety:

  P#2: *"... I'm sure some teachers are still very uncomfortable being in a room all day with 20 kids. So, I think that some would prefer having that airflow as an act of safety."*

  P#5: *"....it drives me crazy, as we have a girls' bathroom in our hallway, and there are windows in that bathroom, but they have screwed them close … I am assuming for safety. But if we needed to get out for whatever reason, you can't. I mean, the kids would be trapped in that bathroom …."*

- Connection to Nature: P#6: *"... I think the kids do need to have lots of different sights and sounds… so they're able to notice butterflies and bugs … and notice the smell too. If you open the window and it's raining, there's certainly a different smell to it than when it's dry. So, they do notice those kinds of things…."*

- Student Learning Performance: P#4: *"...I wish I did have operable windows so that I wouldn't have to have [students] standing right outside of my room to use [musical instruments] … They have to have more airways…."*

Drawbacks:

- Security:

  P#1: *"... But honestly, because of lockdown and school shootings and the violence, I don't think even if we had operable windows, [school administrators] would let us open* *them …. So, it's like we live in this world [where] simple things that would be awesome, like getting in a little fresh air in the middle of the day, is not possible*."

P#3: *"... I also worked in schools that had that the windows that were opened, and we had a lot of break-ins, so that's why I'm not really a big fan of open windows*."

P#7: *"...a legitimate security risk, is if they [operable windows] don't get closed, leaving them open overnight, etc*.,"

- Health and Safety:

  P#1: *"...maybe a kid is trying to get out of it and hurting their arm ... because kids can be mischievous ... so just like safety ..."*

  P#6: *"...We usually, honestly, don't open [operable windows] that much… I do have some kids with some allergies ..."*

- Animals and insects

  P#1: *"... the animals crawling in the windows.... I've had operable windows, but I've never actually opened them because you're always told don't open them ... because they didn't want bugs to come in, or grass or people or animals or whatever, so I wasn't allowed to open them ..."*

  P#5: *"... I had a bird fly in [the classroom] last year. That is exciting! And I asked if I could put a screen ... and they said no because it's the emergency exit …."*

- Indoor Air Quality: P#7: " ... *Certainly, there are areas where the fresh air is not healthy, and then we wouldn't necessarily want to just bring in the fresh air… if you have the school next to the highway, and lots of trucks are going by, you don't necessarily want to breathe that in unfiltered…."*

- HVAC Performance: P#8: *".... there's kind of an unwritten rule. If the air conditioning is on, don't have the windows open because you're throwing that money [you spent on electricity to cool your space] out of that window ... You may be creating more issues because the air that you're bringing in might be really humid ...".*
- Students' Performance: P#2: "*So, me being on [name of the road], if I had an open window, you might hear the traffic all day. So, I don't know if I could use it anyway, with all that noise, honestly...."*

Air Purifiers

In light of COVID-19, several conversations included air purifiers as IAQ strategies to safely reopen schools. Due to the time limitation of the interviews, two teachers and one engineer were asked about the benefits and drawbacks of air purifiers. The benefits of air purifiers include providing a healthier IAQ during COVID-19 and added benefits for students with asthma. The drawbacks of air purifiers from teachers' perspectives include space limitation and student distraction; the noise of the air purifiers' operation could impact student learning performance. Also, one engineer emphasized the importance of education around air purifiers in schools. The presence of air purifiers might lead occupants to feel comfortable enough to remove their masks though the filters may either not be working well or are not actually big enough to serve the entire space. Some of the benefits and drawbacks of air purifiers mentioned by interviewees are shared below.

Benefits:

P#3: *"[one of the benefits is related to] COVID. I think anything you can get to help would be great. We have so many asthmatics, and we have so many students that have so* *many issues. I think if we could really try to eliminate as many barriers as we possibly can to make sure that everyone feels healthy, I think that would be great."*

P#5: *"I would feel more comfortable if I have [air purifiers] in our classrooms … not just with COVID, but also just because our buildings are old. And I think for the health of all of us, it would be better if we had one in every classroom ..."*

P#7: *"We have put one in two specific places in our district: one is in sick rooms, so if a kid at school tests positive while at school, and they have to be quarantined for a couple of hours until the parent comes and picks them up. Because that's a small space and the air needs to be cleaned. So, we get high-quality [air purifiers] that we believe are working and functional. And we can change those filters. It's only a few of them. It's not 3000 of them. And in places where we cannot get high enough fresh air in through mixed air or through air changes, investing in the right [purifier], scientifically-backed ones, I think, are absolutely useful. So, I think they have to be used strategically ..."*

Drawbacks:

- Noise and distraction

  P#3: *"No [there are not any drawbacks for air purifiers], I mean as long as it's a quality one. It's not that loud ..."*

  P#5: *"... I'm sure there are some that are noisy, and so, I think that would be an issue, just trying not to distract the children..."*

- Space limitation

P#5: *"[one of the drawbacks is] space. Because if you need one that's big enough to effectively work in a classroom … And our classrooms are tight on space…."*

- Being utilized suboptimally

  P#7: *"...There are a very wide range of products out there and getting a bad product or the wrong product, or non-effective product is going to increase one's sense of comfort, while not improving actual health and safety, which I [consider] to be significantly dangerous. Perceived safety and comfort in something like this ... are very problematic. They have filters that need to be changed, and unless they're being changed, they become completely useless after a short period of time. But again, then you have something in there that you think is working, that it's not, you're like, maybe I'll take my mask off for a few minutes..."*

Discussion

This paper aims to understand (1) how teachers interact with their classrooms to improve IAQ in PreK-5 schools before and during COVID-19, (2) how school buildings and policies support or limit those behaviors, (3) benefits and drawbacks of those interactions from teachers' and engineers' perspectives, and (4) how to mitigate drawbacks while enhancing benefits of different strategies. This paper aims to provide different stakeholders a holistic and comprehensive understanding of IAQ-related behaviors and their impact on various aspects of students, teachers, and buildings. This study is a part of an exploratory mixed method case study on behaviors to improve IAQ and thermal comfort in elementary schools in the United States. It includes surveys with teachers and interviews with teachers and engineers in charge of HVAC systems in elementary schools. In this study, 27 teachers participated in a survey, and eight participants (six teachers and two engineers) were interviewed. The current paper only includes data related to behaviors improving IAQ in classrooms.

The results of surveys show that the percentage of teachers who think the IAQ in their classrooms is excellent or good has decreased during the pandemic (Figure 2.4). When further discussed in interviews, teachers share that their perception of classroom IAQ is almost the same before and during COVID-19. Thus, the decrease in percentages of teachers in the survey who think their IAQ is excellent/good during the pandemic compared to before it might be because more teachers responded “Not Applicable” to this question during the pandemic; many teachers were not in their classrooms to be able to answer this question appropriately.

Also, in the survey, teachers were asked how they improve or would like to improve IAQ in their classrooms before and during COVID-19. The results show that 53% of surveyed teachers and all interviewed teachers prefer to use operable windows to improve IAQ both before and during the pandemic; 44% of the survey respondents used operable windows before the pandemic. In comparison, this number increased to 56% during COVID-19 since teachers would like to have more fresh air during the pandemic to provide a safer and healthier environment for their students and themselves. These numbers align well with recently suggested strategies to use operable windows to mitigate the risk of COVID-19 (CDC, 2021c; WHO, 2020b; AIA, 2020; ASHRAE, 2021).

Moreover, 26% of surveyed teachers mentioned using air purifiers to improve IAQ in their classrooms in their optional comment field in the survey. Also, a few teachers mentioned the importance of cleaning practices and changing HVAC filters in improving IAQ in schools. Some teachers also stated that they would use fans to circulate air to improve IAQ; air circulation is mainly a factor of thermal comfort, which is not the focus of this study. Furthermore, some interviewees mentioned the importance of utilizing outdoor spaces for activities; outdoor activities often help schools to provide a healthier environment for students and teachers in terms of air quality while increasing their connection to nature and other benefits around learning performance. Thus, the teachers' preferred interactions with their classrooms to improve IAQ are to use operable windows and air purifiers.

Since all building elements and related behaviors come with pros and cons, it is essential to be aware of the context of using operable windows and air purifiers in schools, engaging windows strategically to enhance benefits and mitigate drawbacks. The survey and interview results show that all interviewees and more than half of survey respondents believe that operable windows would improve IAQ by providing fresh air in the classrooms. In addition, participants believe that operable windows have other benefits such as (1) improving thermal comfort, (2) improving health and safety in terms of both COVID-19 and emergency situations, (3) providing connections to nature, and (4) improving student performance. On the other hand, operable windows have some drawbacks that prevent teachers from using them and dissuade engineers from considering operable windows in their system design and operation. This study indicates that participants think that operable windows have the following drawbacks: (1) interfering with security in terms of shootings and violence, (2) interfering with health and safety such as kids falling and seasonal allergies, (3) crawling animals and insects coming inside the classrooms, (4) IAQ negatively impacted from outdoor pollution , (5) interfering with HVAC performance by putting an unexpected load on the system, and (6) interfering with students' performance through factors such as outdoor traffic noise.

An air purifier is another preferred interaction that several teachers mentioned in both surveys and interviews. Many said that they would like to have purifiers in their classrooms to support a healthier environment for students, especially during the pandemic and particularly for those with asthma. However, air purifiers also come with some drawbacks. Two teachers and one engineer were asked about the disadvantages of air purifiers in schools. Teachers mentioned that they would take up space in already tight the classrooms, and their noise might distract students and impact their learning performance. The engineer mentioned that having a low-quality air purifier might create a false sense of safety and lead occupants to remove their masks. The engineer emphasized that it is essential to strategically provide air purifiers and maintain them in smaller spaces such as sick rooms. Thus, in this type of application, the air purifier and filter replacements seem to be feasible and not expensive.

Furthermore, different stakeholders play a role in enhancing the benefits of operable windows and air purifiers while mitigating their drawbacks. Based on the benefits and drawbacks mentioned in the Results section, Table 2.3 shows proposed strategies for different stakeholders to improve IAQ in schools while mitigating the disadvantages of IAQ-related behaviors, specifically opening/closing windows and using air purifiers. As shown in Table 2.3, eight stakeholders play a direct role in effectively providing, installing, and utilizing operable windows in classrooms. These stakeholders include (1) window manufacturers, (2) software engineers/UX designers, (3) urban planners, (4) architects, (5) HVAC/mechanical engineers, (6) school administrators, (7) teachers, and (8) students. Also, HVAC engineers and school administrators play an essential role in providing and installing a proper air purifier in schools and maintaining quality operation. Since some interviewees mentioned outdoor learning spaces, results suggest considering designing and utilizing outdoor spaces for different school activities, which would help reduce the concerns of teachers and students about COVID-19 while improving a connection to nature.

Table 2.3: Strategies for providing high IAQ in indoor spaces

	Stakeholders/Strategies

Operable Windows	Window Manufacturers:
	● Design and manufacturer windows which are:
	    ○ Customizable based on the user needs.
	    ○ Easy to open/close.
	    ○ Securely lockable.
	    ○ Have or can have a screen.
	    ○ Easy to clean and maintain.

	Software Engineers/UX designers:
	● Design a way to:
	    ○ Tell teachers when a good time is to open/close windows based on indoor and outdoor conditions.
	    ○ Remind teachers to close windows when leaving (an app on their phone device or indicators in the class/windows)

	Urban Planners: Zone schools far from highways with traffic giving architects more freedom to locate windows that can be open/close without any traffic disturbance.
	Architects: ● Locate classrooms around less disturbing noise such as traffic noise, etc. ● Design classrooms with at least two operable windows (preferably on opposite sides) to provide cross ventilation. ● Design classrooms adjacent to a single loaded corridor to provide adequate cross ventilation through two windows located in opposite sides ● Keep daylight, safety (emergency exit and kids falling), and security (not letting people in) in mind when locating the windows. ● Have secured locked windows, which are easy to open/close and clean, and have a screen to prevent animals and bugs from crawling in. ● Provide windows along with a tool to remind teachers to close them. ● Educate teachers on how they can use their classrooms to improve IAQ while mitigating potential drawbacks of their behaviors.
	HVAC/Mechanical Engineers: ● Provide sensors or indicators to let teachers know when a good time is to open/close windows and remind teachers to close windows when leaving. ● Design system which considers the status of windows (open/close). ● Educate teachers on how they can use their classrooms to improve IAQ while mitigating potential drawbacks of their behaviors on HVAC performance.

Table 2.3 (continued): Strategies for providing high IAQ in indoor spaces

	School Administrators: Provide training sessions for teachers about the benefits and drawbacks of operable windows and how to use them effectively.
	Teachers: ● Remember to close and lock the windows when leaving the classroom (i.e., by using notes/asking students to remind them/etc.) ● Be more aware of the impact of their interactions on building systems and students. ● Attend training sessions to learn about the impact on classrooms and students.
	Students: Learn how to interact with spaces to improve IAQ in classrooms.
Air Purifier	School Administrators/HVAC Engineers ● Install suitable air purifiers based on the size of the room. ● Provide less noisy air purifiers. ● Change air purifier filters frequently.
General Design	Architects/School Administrators: Consider designing and providing outdoor spaces for learning and eating activities.

Since these strategies are based on an exploratory study with 27 survey respondents and eight interviewees, future research should expand this study to other stakeholders and schools to suggest transferrable and practical strategies to mitigate the drawbacks of IAQ-related behaviors and enhance their benefits. Thus, this paper suggests conducting more interdisciplinary mixed methods studies that include different stakeholders to (1) improve their awareness about their role in elevating IAQ in schools, (2) increase awareness about other stakeholders' needs and perspectives about IAQ-related behaviors, and (3) provide actionable and practical suggestions to mitigate the drawbacks of these behaviors and improve benefits. It is suggested to conduct surveys, interviews, focus groups, and brainstorming sessions with diverse stakeholders such as architects, school administrators, mechanical engineers, teachers, window and air purifiers manufacturers, software engineers, UX designers, and students.

Conclusion

School environments impact student comfort, health, and performance (Abramson et al., 2006; Annesi-Maesano et al., 2013; Almeida et al., 2016). Studies show the importance of IAQ and ventilation rates in schools when addressing student health and learning performance (Wargocki et al., 2007; Daisey et al., 2003 Haverinen-Shaughnessy et al., 2011). After COVID-19 hit the world in early 2020, leading agencies such as CDC, WHO, AIA, and ASHRAE published guidelines to more safely reopen schools during the pandemic (CDC, 2021c; WHO, 2020b; AIA, 2020; ASHRAE, 2021) given the essential role of schools in the country's economy and students' lives (Kiernan, 2020; Kniffin et al., 2021). The research published by CDC shows the importance of providing adequate outdoor air ventilation and clean air in spaces to mitigate the risk of exposure to COVID-19 as compared to surface sanitization (CDC, 2021b). frequently using operable windows and changing HVAC filters has been prioritized to safely reopen schools (CDC, 2021c; WHO, 2020b; AIA, 2020; ASHRAE, 2021). Also, studies show that an adequate ventilation rate can improve student learning performance and outcomes in the classroom (Gao et al., 2014; Wargocki and Wyon, 2007; Satish et al., 2012). Unfortunately, previous studies show inadequate ventilation rates in K-12 classrooms (Mendell et al., 2013; Mendell and Heath, 2005; Haverinen-Shaughnessy et al., 2011; Daisey et al., 2003), which is contrary to focus areas to safely reopen schools during the pandemic. Studies do show that opening/closing windows might have drawbacks such as outdoor noise and pollution (Goins et al., 2012), making teachers and other stakeholders cautious to use operable windows to improve IAQ in their classrooms. Thus, this study aims to establish a more comprehensive understanding of teachers' preferred behaviors to improve IAQ in their classrooms, the benefits and drawbacks of those behaviors, and suggestions for different stakeholders to mitigate those drawbacks while enhancing benefits. This study is a part of a larger exploratory case study focusing on thermal comfort and IAQ in schools.

This study includes surveys and interviews to create a holistic view of IAQ-related behaviors, along with their perceived benefits and drawbacks. Four schools participated in this study: three in North Carolina (two PreK-5 schools, one K-5 school) and one in Illinois (PreK-8 school). Teachers at four schools participated in an online survey. Unfortunately, due to COVID-19, the survey response rate was not high with only 27 responses total. Also, eight participants participated in interviews (six teachers and two engineers).

This study shows that most surveyed teachers would like to open windows to improve IAQ in their classrooms. Several teachers also mentioned the importance of air purifiers, cleaning practices, and changing HVAC filters to enhance IAQ in their classrooms. Participants in both surveys and interviews were asked about the benefits and drawbacks of different IAQ-related behaviors, including operable windows and air purifiers. In addition to improving IAQ, some of the benefits of using operable windows are enhancing (1) thermal comfort, (2) health and safety, (3) connections to nature, and (4) student performance. The drawbacks are (1) interfering with security, (2) interfering with health and safety, (3) allowing crawling animals and bugs into the classrooms, (4) interfering with IAQ, (5) interfering with HVAC performance, and (6) interfering with students' performance. Also, participants mentioned that air purifiers would support a healthy environment for students, especially during the pandemic and for the ones with asthma. On the other hand, participants shared some drawbacks of air purifiers such as (1) occupying valuable space in the classroom, (2) having noise that distracts students, and (3) possibly causing a false sense of safety by encouraging occupants to remove their masks.

Moreover, some interviewees mentioned the importance of utilizing outdoor spaces for different activities to increase feelings of safety while improving the connection to nature for students.

To mitigate the drawbacks of operable windows and air purifiers, this study suggests strategies for different stakeholders to design, maintain, and use to enhance benefits and reduce disadvantages effectively and adequately. The proposed strategies for various stakeholders to improve operable windows performance include (1) urban planners zoning schools far from highways and traffic noise; (2) architects to locate classrooms far from traffic noise, design classrooms with two windows on the opposite sides and adjacent to a single loaded corridors, and utilizing securely locked windows with screens; (3) HVAC/mechanical engineers to consider variable window status (open/close) in their system designs and calculations; (4) teachers to remember to close windows when leaving; (5) window manufacturers to design and manufacture customizable, securely lockable, easy to use and maintain windows; and (6) software engineers/UX designers to design tools to remind teachers when they should open/close windows. This study also suggests that architects and school administrators provide training workshops and classes to teachers and students to teach them how to use buildings operations to improve IAQ while mitigating potential drawbacks of their behaviors. Moreover, this study suggested that school administrators and HVAC engineers install right-sized air purifiers that are less noisy and frequently change filters. In the end, this paper suggests expanding data collection. More interdisciplinary mixed methods studies should include increased categories of stakeholders to understand differing perspectives on IAQ-related issues, and suggest robust, transferrable practical strategies to mitigate the drawbacks of these behaviors while enhancing their benefits.

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3. CHAPTER 3: Benefits and Drawbacks of Teachers' Behaviors to Improve Thermal Comfort in Elementary Schools in the United States: Suggestions for Stakeholders and Future Studies

Abstract

Schools are an essential part of children's lives and impact student comfort, health, and performance. Thermal comfort has the highest impact on human comfort and is related to student learning performance in schools. However, because people can feel thermally different in similar environmental conditions, they may prefer different ways of interacting with built environments to improve their comfort. This paper outlines an exploratory mixed methods case study focusing on teachers' preferred behaviors to improve thermal comfort in their classrooms, identifying benefits and drawbacks through surveys and interviews. Twenty-seven survey respondents and eight interviewees from four elementary schools participated in this research. The results show that teachers prefer to open/close windows and shading devices, turn on/off fans, and adjust thermostat temperatures to improve classroom thermal comfort. The results also indicate that each of these comfort-related behaviors comes with pros and cons. Because occupants play a role in effectively using windows, shading strategies, fans, and thermostats, this study recommends strategies for different stakeholders to mitigate the drawbacks of each behavior while enhancing potential benefits. This paper establishes a holistic and foundational knowledge knowledgebase about the stakeholders' role in facilitating a thermally comfortable classroom environment while mitigating potential drawbacks of comfort-related behaviors.

Keywords: Elementary Schools, Thermal Comfort, Teachers' Behaviors, Benefits and Drawbacks, Suggestions, Different Stakeholders

Introduction

Children spend most of their time in schools (Catalina and Iordache 2012), making schools the second most important environment in children's lives after their homes (Bako-Biro et al., 2012.; Mendell et al., 2013). Studies show that indoor environments have a relationship with student comfort (Mendes et al., 2014) and learning performance (Wargocki and Wyon, 2006; 2007; Shendell et al., 2004; Haverinen-Shaughnessy et al., 2011; Dias et al., 2011), with comfort being one of the most critical parameters in student learning performance (Wargocki and Wyon, 2007). ASHRAE Guideline 10P (2010) categorizes human comfort conditions in four major groups: thermal, visual, acoustics, and indoor air quality (IAQ). This ASHRAE Guideline studied interactions among these four groups of conditions in buildings. For instance, architects may design buildings that use natural ventilation through operable windows to moderate indoor temperature and maintain air quality (thermal and IAQ). However, if the outdoors are noisy or polluted (acoustics and air quality), people may not prefer to open windows. Here, design solutions that intend to control one element of the environmental may cause problems in other conditions. Because thermal comfort has the greatest impact on human comfort, the change in thermal condition also has the greatest impact on comfort levels compared to the other three influences (Frontczak and Wargocki, 2011). Also, uncomfortable thermal environments have been correlated with decreased student learning performance and increased absenteeism in the classroom (Wargocki and Wyon, 2006; 2007; Shendell et al., 2004; Haverinen-Shaughnessy et al., 2011; Dias et al., 2011).

Different sources produce heat in buildings including occupants, lights, equipment, and daylight. If the heated air is not exchanged with cooler air, either from outside or from the cooling system, the indoor air often becomes overheated and thermally uncomfortable (Ilyas et al., 2012). On the other hand, individuals have different levels of thermal comfort, resulting in comfort variations in the same thermal conditions (ANSI/ASHRAE Standard 55, 2017). These variations in comfort may encourage occupants to modify their spaces through a range of interactions with their environments to improve the thermal comfort. Two models commonly used internationally to discuss thermal comfort are the (1) “rational” model and (2) “adaptive” model (Martinez-Molina et al., 2017). The “rational” model is the work of Fagner, who created the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). PMV is an index predicting the consensus of comfort for a large group on a 7-point thermal sensation scale, while PPD indicates the percentage of individuals who experience discomfort (Fagner, 1970). “Adaptive” models focus on people adapting and improving their thermal environments by interacting with building controls, such as opening/closing windows/doors, turning on/off fans, etc., as well as themselves personally, such as changing clothes, having hot/cold drinks, etc. This “adaptive” model is the most realistic in buildings, particularly for natural ventilation (Stazi et al., 2017). Brager et al. (2004) suggest that it is essential that occupants play an active role in indoor climate feedback loops to control their environment. The “adaptive” model has been studied primarily on office buildings and with adults (Liang et al., 2012). There is a lack of studies on adaptive behaviors in other building types, including schools.

Studies also show that people with control over their environment, such as the ability to open/close windows and change thermostat temperatures, tolerate higher temperature ranges (Brager et al., 2004; Mishra and Ramgopal, 2015; Buonocore et al., 2019; Jindal, 2018) and feel better both mentally and physically (Shapiro and Astin, 1998; Taylor and Brown, 1988) compared to those without control.

Since occupants have different preferences for comfort, individual behaviors might differ from others in the same built environment context. Various decision-making factors impact human-building interactions, including environment, time, and psychological factors (Balvedi et al., 2018). Several studies have been conducted on behaviors to improve student comfort, including opening/closing windows (Yang and Zhang, 2008; De Giuli et al., 2012; Dias Pereira et al., 2014; Gao et al., 2014; Stazi et al., 2017; Almeida et al., 2017). However, most of these studies have not focused on improving occupant thermal comfort in K-12 schools. Moreover, these studies relied on quantitative methods such as student surveys and environmental monitoring in classrooms and were only held in Europe and Asia. Also, despite the autonomy of teachers and staff to interact with the classroom environment to support occupant thermal comfort, and thereby learning performance, a few studies focus on teacher and staff decision-making for these environment interactions. To address this gap, this research utilized surveys and interviews to understand teachers' preferred behaviors to improve IAQ in schools in the United States.

The World Health Organization (WHO) declared COVID-19 a pandemic in March 2020 (WHO, 2020a) and established the virus as an ongoing issue in May 2020 (BBC, 2020). The virus negatively impacts businesses and schools worldwide (Chick et al., 2020). People became more aware of the impact of their built environment on their health during the pandemic. Also, individual preference and decision-making processes to improve thermal comfort might have changed during the COVID-19 pandemic. However, there is no adequate information on behaviors and decision-making process in schools and how they might have changed during the pandemic.

Several leading agencies such as WHO, the Centers for Disease Control and Prevention (CDC), and the American Institute of Architects (AIA) published guidelines to reopen schools in the United States safely. All these guidelines suggested increasing outdoor ventilation and ventilation rates in spaces through operable windows, fans, and installing proper HVAC filters. In a typical classroom, teachers can control environmental conditions based on the school's construction and orientation, HVAC design, and school or system policies. This paper focuses on how teachers are prioritizing their interactions with their classroom environments before and during COVID-19; increasing fresh air in the classrooms is important to address health in classrooms during the pandemic (CDC, 2021a; WHO, 2020b; AIA, 2020; ASHRAE, 2021) while improving thermal comfort (Wargocki et al., 2002; Shendell et al., 2004; Daisey et al., 2003; Bartlett et al., 2004). Inherent challenges in strategies to improve thermal comfort are also important to understand (Balvedi et al., 2018), particularly in learning environments.

This paper focuses on thermal comfort and is a part of an exploratory case study addressing teachers' preferred behaviors to improve thermal comfort and IAQ in their classrooms. According to CDC, in January 5, 2022, 62.3% of the US population had been fully vaccinated (206.8 million) (CDC, 2022). However, the effectiveness of current COVID vaccines on new arrival variants (i.e., Delta and Omicron) is unknown (CDC, 2021b). Considering the importance of schools in children's social and academic development, as well as the nation's economy, this study suggests recommendations to improve elementary classroom environments during the pandemic while improving thermal comfort.

The objectives of this paper are to (1) identify teachers' preferred behaviors to improve thermal comfort in their elementary school classrooms, (2) understand the influences on teachers initiating those behaviors, (3) elaborate on drawbacks and benefits of the most common teacher behaviors to improve thermal comfort, which emerge from surveys and interviews, and (4) suggest strategies for different stakeholders to effectively support preferred comfort-related behaviors. The research questions of this study are (1) How have teachers interacted with their classrooms to improve thermal comfort in K-12 schools before and during COVID-19? and (2) What are the benefits and drawbacks of using operable windows, shading devices, fans, thermostats, and other personal behaviors to improve thermal comfort in classrooms?

Methods

This paper is a part of a Ph.D. dissertation focusing on human-building interactions, thermal comfort, and IAQ in elementary schools in the United States. A separate article addresses the topic of IAQ. This paper only focuses on behaviors around improving thermal comfort, possible benefits and drawbacks, and suggestions to different stakeholders. This study includes surveys and interviews with teachers, as well as engineers in charge of HVAC systems in schools.

Case Study

Participants of this study worked in four schools located in North Carolina and Illinois. Table *3.1* shows the characteristics of each school. To ensure anonymity, schools are designated by letters A to D. The researchers' connections with schools' principals and architects led to the purposive selection of cases; after IRB approval, school administrators agreed to participate in the data collection during the pandemic. Data collection included surveys and interviews conducted between March – September 2021 .

Table 3.1: Properties of schools in this study

School	City	Year built	Grade	Student #	Operable Window	Shading	Fan	Controllable Thermostat
School A	Raleigh, NC	2019	PreK-5	425	No	Horizontal Blinds	No	No
School B	Raleigh, NC	2011	PreK-5	590	Yes (with some exceptions)	Horizontal Blinds	No	No
School C	Durham, NC	1949, 1955, 1995, 2010	K-5	489	Yes	Horizontal Blinds	Yes (Box Fan)	No
School D	Joliet, IL	2018	PreK-8	427	Yes (with some exceptions)	Shade Screen	No	No

Survey

The online survey was created in Qualtrics and included close-ended and open-ended questions. The survey was shared with all teachers at each of these four schools through emails from their administration. Due to the complexity of the COVID-19 school years, surveys were open from March - August 2021. Several reminders were sent during this time. Consent was embedded in the beginning of the survey. After completing the survey, participants were led to a separate page providing an option to participate in a raffle to win one of six $30 Amazon Gift Cards (per school) and interest in a follow-up online interview. These questions were separate to maintain the anonymity and confidentiality of the survey data.

To ensure that the survey questions would be perceived by respondents as planned, the team conducted a pilot study to test the questions. A local elementary teacher associated with one of the research team recorded herself while responding to the survey and talked aloud about her thoughts and perceptions of each question. The researchers revised and finalized the survey considering the pilot study. A total of 27 teachers across all four schools responded to the survey. Unfortunately, due to the pandemic, the response rates were lower than expected, resulting in a study limitation.

Interviews

Online interviews were conducted through Zoom after the survey and were recorded with participants' permission for transcription. A total of eight interviews were completed, including six teachers and two engineers in charge of HVAC systems in schools. These interviews with engineers provided insight on the benefits and drawbacks of each type of interaction from a facilities and control perspective. Teachers were able to indicate their interest in participating in a follow-up interview at the end of the survey. Two engineers were also invited to participate in interviews through the researchers' connections. Each interview took 1 – 2 hours, and all teachers received a $30 Amazon Gift Card. The interviews included in-depth explorations and clarifications around survey questions and topics.

Analysis

Quantitative Analysis

Since twenty-seven survey participants was not enough for correlational and regression analysis, only a descriptive analysis was conducted for the close-ended survey questions. This study utilized pandas library v. 1.2.4 (Python Analysis Library) to perform data cleaning, descriptive analysis, and plots.

Qualitative Analysis

The qualitative data included open-ended survey and interview questions analyzed in Dedoose Desktop v. 9.0.17 and Microsoft Excel. As Figure 3.1 shows, the qualitative analysis process includes:

1- Transcribing the interviews and removing participants' names to maintain the anonymity.

2- Reviewing the interview transcriptions and open-ended survey responses to better understand initial codes present in the data to answer research questions.

3- Documenting emerging codes from the qualitative data (Phase #1 in Figures 3.1 and 3.2).

4- Revising, dividing, and combining initial codes to fully capture themes present in the data (Phase #2 in Figures 3.1 and 3.2).

5- Using qualitative data and emergent codes to support the descriptive analysis and suggest future research.

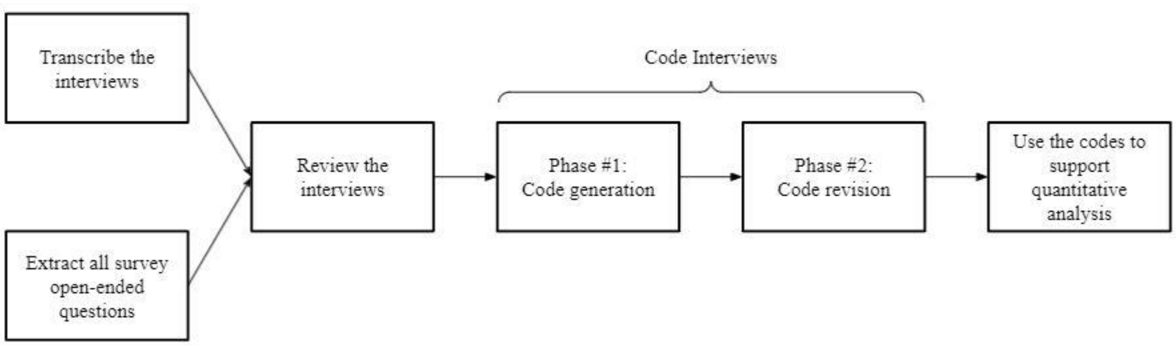

Figure 3.1: Qualitative coding and analysis process

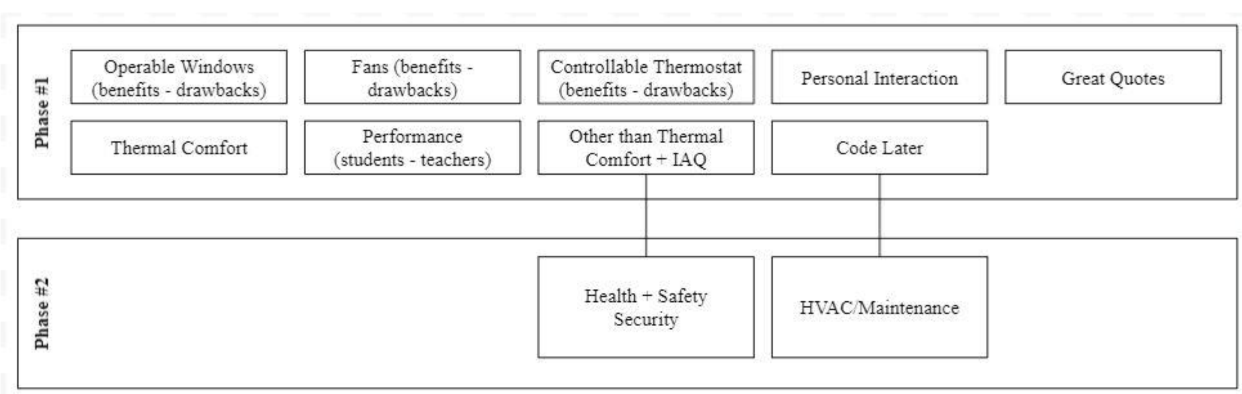

Figure 3.2: Qualitative codes

Results

Participant Demographics

The demographics of survey respondents (27 teachers) and eight interviewees (six teachers and two engineers) participated in this study will be discussed in this section.

Survey participants

- 33% (9) from School A; 11.1% (3) from School B; 22.2% (6) from School C; 33% (9) from School D.
- 74% (20) are primary grade teachers, and 26% (7) are specialist teachers.
- 15% (4) are between 56-65 years old; 37% (10) are between 46-55 years old; 22% (6) are between 36-45 years old, 22% (6) are between 26-35 years old, and 4% (1) are between 18-25 years old.
- 89% (24) are women, and 11% (3) are men
- 67% (18) are White, 19% (5) are Black, 11% (3) are Hispanic, and 4% (1) preferred not to answer.

Interview participants

Interviewees included three teachers from School A, one teacher from School B, one teacher from School C, one teacher from School D, and two engineers (project manager and energy engineer) in the school district of School C (Table 3.2).

Table 3.2: Interviewee characteristics and their schools

Participants	Schools	Experience	Operable Windows	Fans	Shading	Controllable Thermostat
P#1	A	13 years	No	No	Horizontal Blinds	No
P#2	A	16 years	No (a door to the outside)	No	Horizontal Blinds	No
P#3	A	20 years	No	No	Horizontal Blinds	No
P#4	B	2 years	No (a door to the outside)	No	Horizontal Blinds	No
P#5	C	25 years	Yes (horizontal sliding)	Yes	Horizontal Blinds	No
P#6	D	14 years	Yes (vertical sliding)	No	Shade Screen	No
P#7	Project manager (P#7) and energy engineer (P#8) in the School C district.					
P#8						

Activities in the Classrooms

Since student activities impact thermal comfort, and because policies exist around permitted activities in the classroom due to COVID-19, teachers were asked to choose all activities present in their classrooms before and during COVID-19 (Figure 3.3). Teachers noted that sitting (93%), standing (89%), and playing (89%) were the most common activities before COVID-19, followed by eating (74%) and singing (67%). Sitting and standing remain the most mentioned activities by teachers during the pandemic (70% and 63%, respectively), followed by playing (41%), eating (41%), and singing (30%). These lower percentages were expected given COVID-19 policies around activities such as playing, singing, and eating in the classroom to mitigate viral transmission.

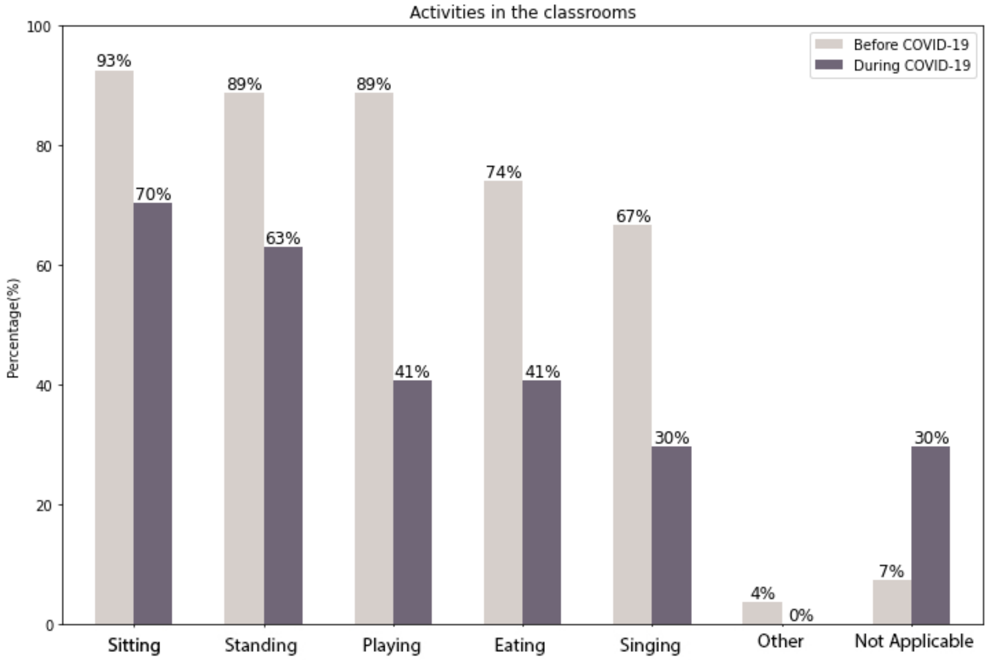

Figure 3.3: Activities in the classrooms (before and during COVID-19)

Teachers' Control Over Their Classroom Environment

Figure 3.4 shows the percentage of teachers who have one of three main interactions with their classrooms: operable windows, fans, and/or thermostats. The image also indicates if participants like having these elements or wish to have access to these interventions. Results show that teachers like control over their classrooms and want to have more control to improve thermal comfort. All participants either like having operable windows or wished/somewhat wished to have operable windows in their classrooms (Figure 3.4). In terms of fans, only 5 participants (18% of total participants and 23% of participants who do not have fans) do not desire fans in their rooms. All other participants either like/somewhat like having fans or wanted/somewhat wanted to have fans in their classrooms. Similarly, all participants either like/somewhat like having a thermostat or wished/somewhat wished to have thermostats in their classrooms.

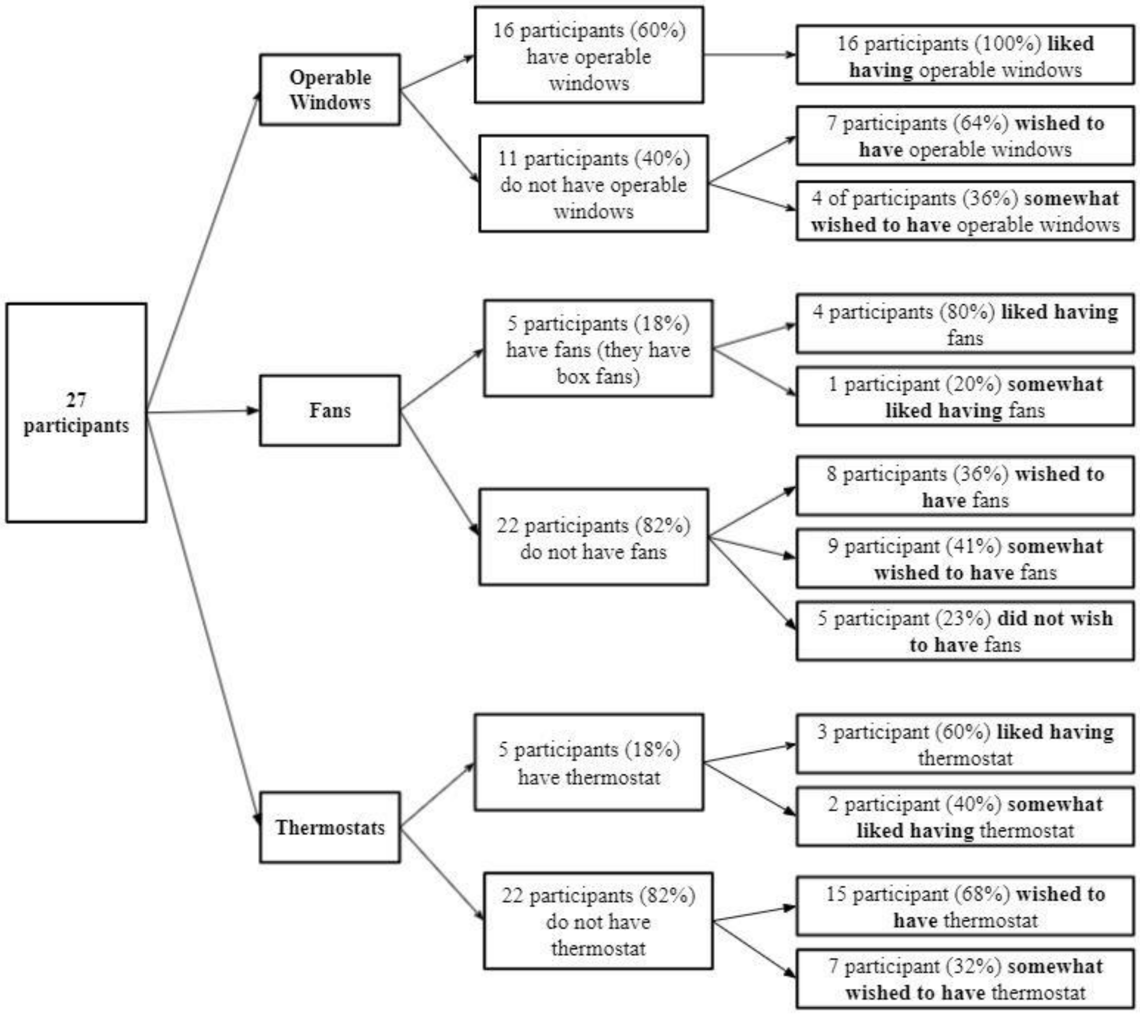

Figure 3.4: Percentage of survey respondents with operable windows, fans, and thermostats, and the percentage that liked having/or wished to have them.

Thermal Comfort in Classrooms

Teachers' Perceptions of Thermal Comfort in Classrooms

Figure 3.5 shows that most of the participants feel thermally comfortable in the classrooms in all four seasons compared to feeling cold/cool and hot/warm. Also, the results show that the number of participants who feel thermally comfortable during Spring and Fall (60% and 63% respectively) are more than ones who feel comfortable in the Summer (37%) and Winter (48%). Figure 3.5 shows that more participants feel cool/cold compared to people who feel warm/hot in their classrooms. Thus, participants are either feeling comfortable or cold/cool in the classrooms throughout the year.

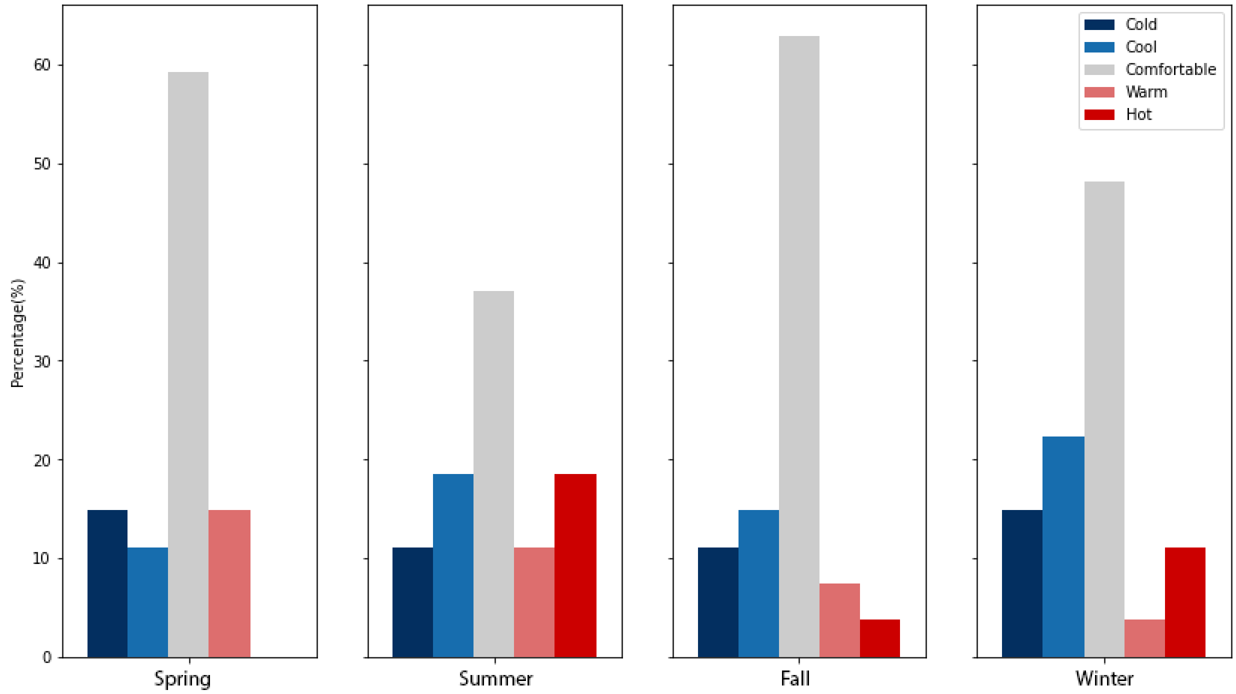

Figure 3.5: Teachers' perception of thermal comfort in their classrooms in different seasons

Actions to Improve Thermal Comfort in Classrooms

This section discusses the results from survey and interview questions asking teachers about preferred interactions with their classrooms to improve thermal comfort, such as when they are feeling cold or hot. Findings are the results of the close-ended survey questions and the open-ended questions from the interview and survey (Figures 3.6 and 3.7). Figure 3.8 aligns survey data with emergent codes from qualitative data, illustrating consistency in the themes across data types.

Behaviors are found to be different when the occupant is hot versus when the occupant feels cold. When hot or warm, as shown in Figure 3.6, most participants prefer the ability to open/close windows (48% before and 41% after COVID-19) and shadings (41% before and 48%

after COVID-19) to improve thermal comfort. The preferred interaction to increase thermal comfort is turning on/off the fans (11% both before and during COVID-19). Switching thermostat temperature was second (7% both before and during COVID-19). In the interviews and open-ended survey questions, participants also mentioned other behaviors to improve thermal comfort for themselves and students when they feel hot. These behaviors include offering water, providing a paper hand fan, using an injury ice pack from the fridge, taking off a layer of clothing (i.e., sweater), and wearing less clothing (i.e., shorts, short sleeve shirts) (Figure 3.8). Some participants also mentioned that they would call the administrators to adjust the temperature of the HVAC systems (Figure 3.8).

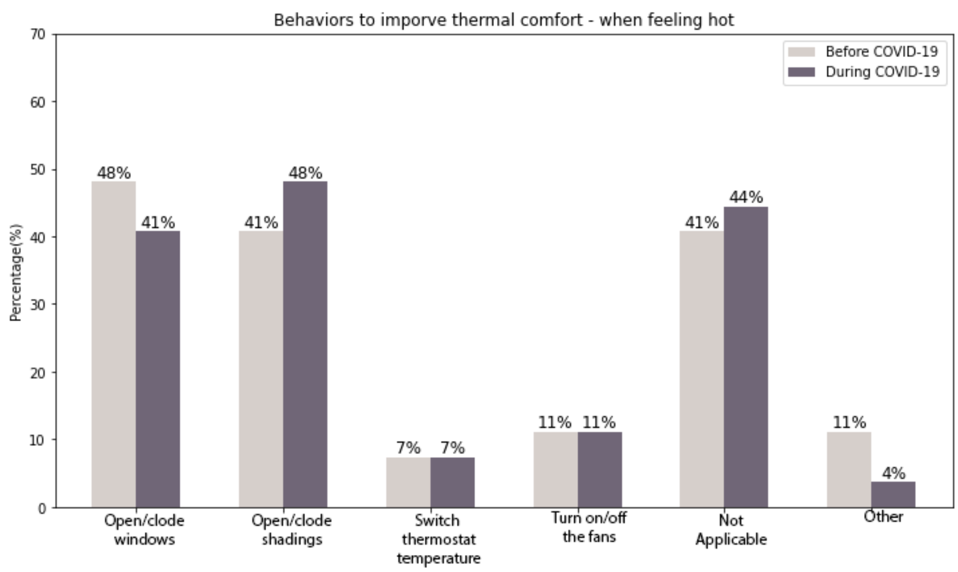

Figure 3.6: Teacher-preferred interactions to improve thermal comfort when it is hot

When cool or cold, as shown in Figure 3.7, most participants would use operable windows to improve their thermal comfort (30% before COVID-19, 33% during COVID-19). The preferred interaction to enhance thermal comfort when feeling cold is opening/closing shadings (22% both before and during COVID-19), followed by turning on/off the fans (11% both before and during COVID-19), and switching thermostat temperatures (7% both before and during COVID-19). In the interviews and open-ended survey questions, many participants also mentioned personal-level interactions, including wearing a sweater or jacket, using a blanket, and changing activities (Figure 3.8). Also, some participants said they would call the administrator's office and submit a work order to change the temperature in the classroom when it is too cold.

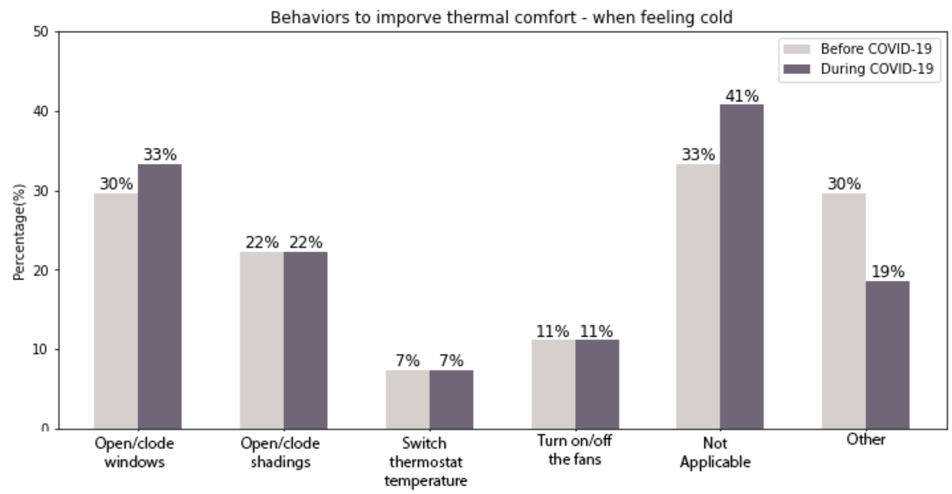

Figure 3.7: Teacher-preferred interactions to improve thermal comfort when it is cold

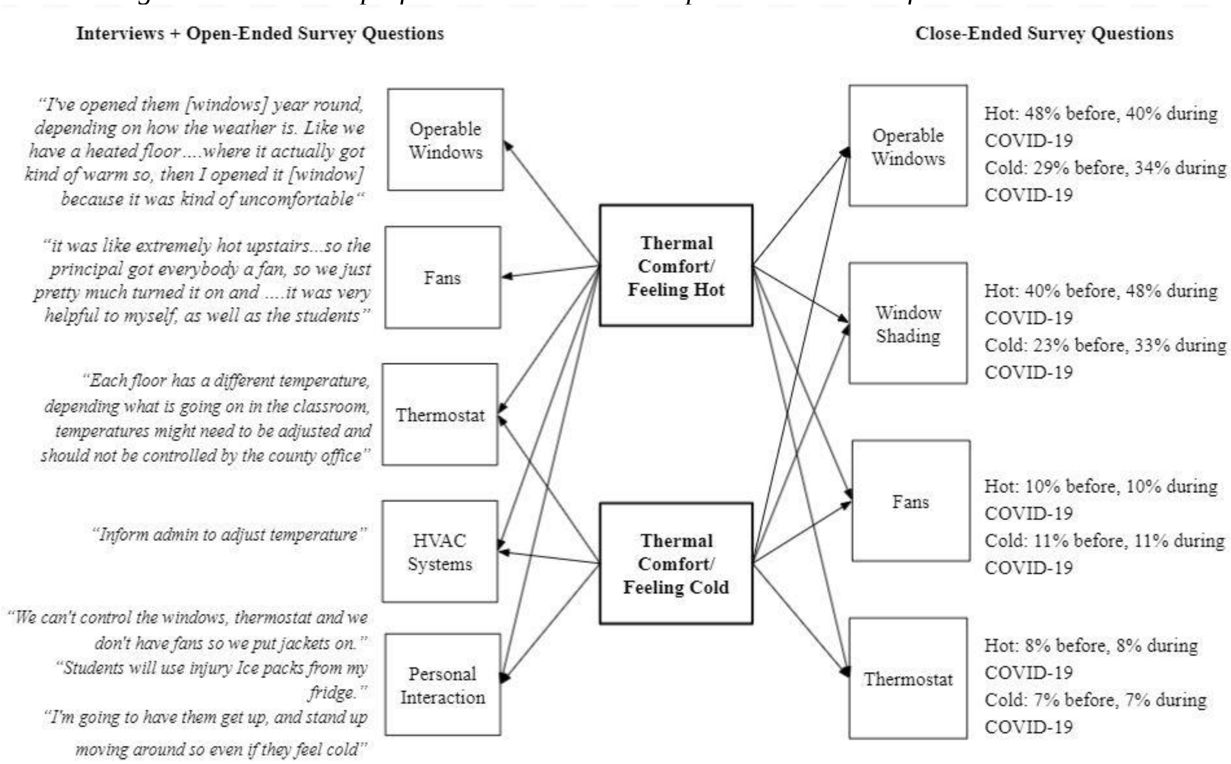

Figure 3.8: Teacher-preferred interactions to improve thermal comfort (qualitative results)

Some interviewees mentioned that a thermally uncomfortable classroom would impact the performance of both students and themselves even if personal-level behaviors are applied (i.e., drink water, wear more/less clothing layers, etc.). Participants' quotes from the interviews include:

- P#2: *"... Not my performance [is being affected by being thermally uncomfortable]. But possibly students, yes. If students are very uncomfortable, they might just choose to sit out and refuse to participate ... If they get too hot, they just give up and say, okay, I'm done..."*
- P#4: *"... for me, it's pretty cold ... I have nerve pain in my right leg, and so I am always wearing that teacher jacket. I also have pain sometimes - it happens if I'm too cold. And it typically happens in my feet to the point where I have to go out to my car, and warm my feet up..."*
- P#5: *"...I think it's more important for the kids to be comfortable because they need to learn and need to be able to do that..."*
- P#6: *"...I think, for some kids, it [being thermally uncomfortable] does make an impact on them because you want them to be comfortable. So, if they're worried about being cold or they're uncomfortable, they're not going to be able to pay as much attention..."*

At the end of the interviews, teachers were asked what they would do to improve thermal comfort in their classrooms if they had all the possible interactions at their disposal. Results show that all teachers would adjust the temperature via thermostat to improve thermal comfort when they feel cold (Figure 3.9). A variety of behaviors, however, are given for improving thermal comfort when occupants feel hot. For example, some teachers first adjust the thermostat, while others first open windows.

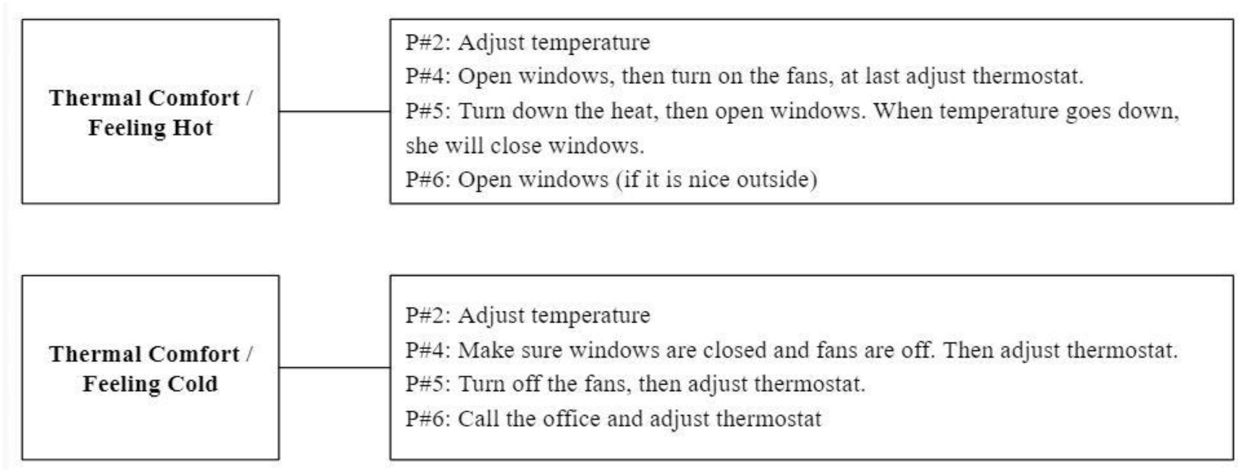

Figure 3.9: Interview results for teachers' preferred behavior to improve their thermal comfort with all options at their disposal

Benefits and Drawbacks of Building Elements

Data shows that most teachers would prefer to use operable windows, fans, controllable thermostats, and shading to improve thermal comfort in their classrooms. This section discusses the benefits and drawbacks of each of these elements, reflecting both survey and interview data.

Operable Windows

The results show that 76% of teachers used operable windows to improve thermal comfort, 70% to improve IAQ and connection to nature, and 30% to improve students' learning performance before COVID-19 (Figure 10, Figure 11). However, during COVID-19, most teachers used operable windows to improve indoor air quality (76%), followed by an intent to improve thermal comfort (50%), connect to nature (45%), decrease the risk of exposure to COVID-19 (50%), and increasing students' learning performance (25%) (**Error! Reference source not found.**). For teachers that do not currently have operable windows, results show that teachers would be interested in using operable windows to improve thermal comfort (55%), indoor air quality (55%), and connection to nature (55%), and followed by decreasing the risk of exposure to COVID-19 (45%) and increasing students' learning performance (20%) (Figure 3.11).

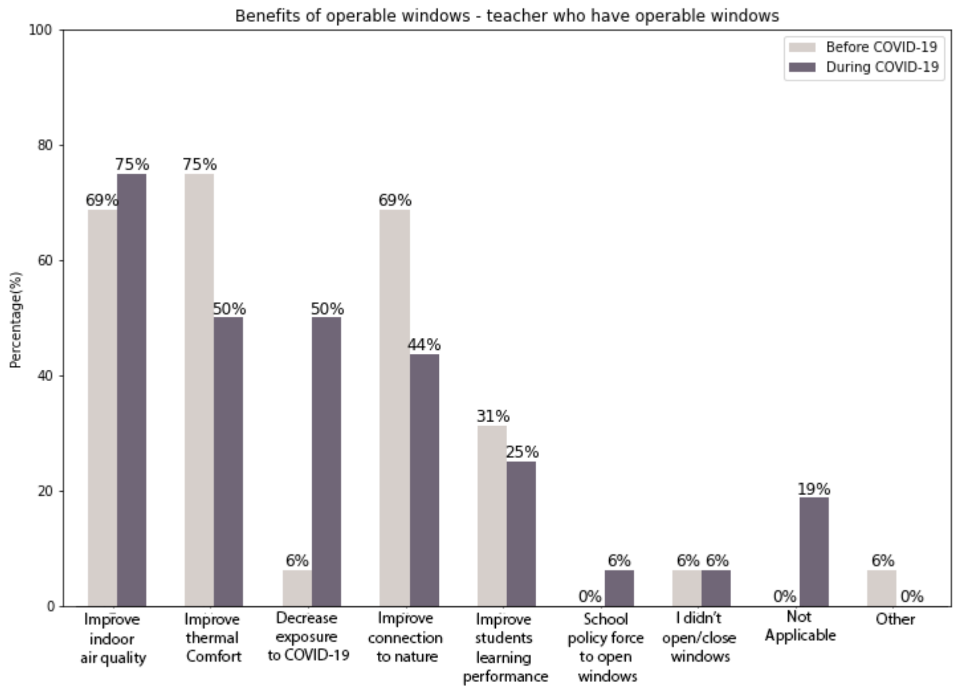

Figure 3.10: Benefits of operable windows - teachers with operable windows

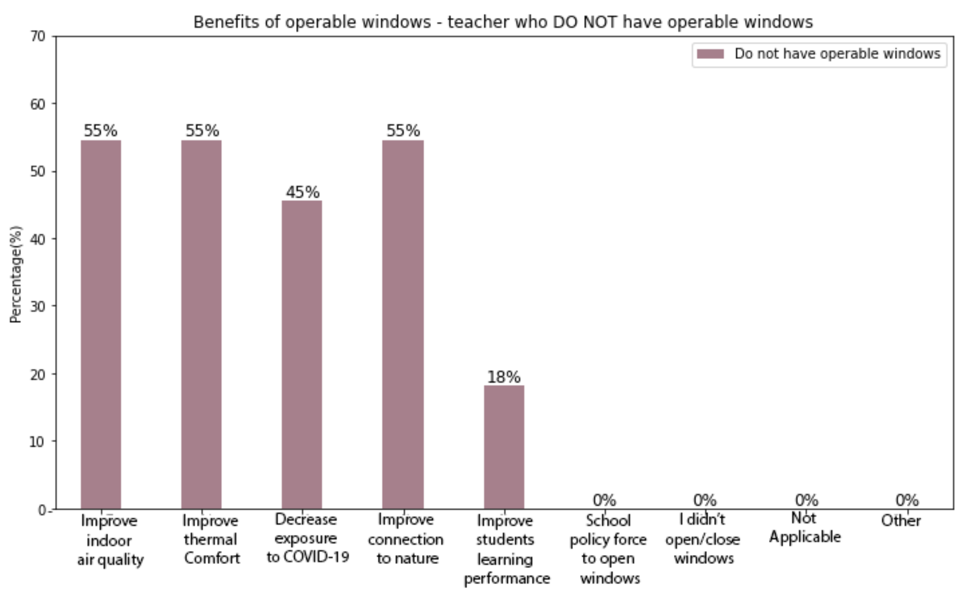

Figure 3.11: Benefits of operable windows - teachers without operable windows

The results to questions about the drawbacks of operable windows show that most teachers who have operable windows (56%) feel that operable windows might negatively impact students' performance due to outside noise and outdoor temperature (Figure 3.12). Most teachers without operable windows (45%) believe that operable windows could increase allergy symptoms due to pollution/pollen (45%), followed by negatively impact thermal comfort due to outdoor humidity (36%) and temperature (36%).

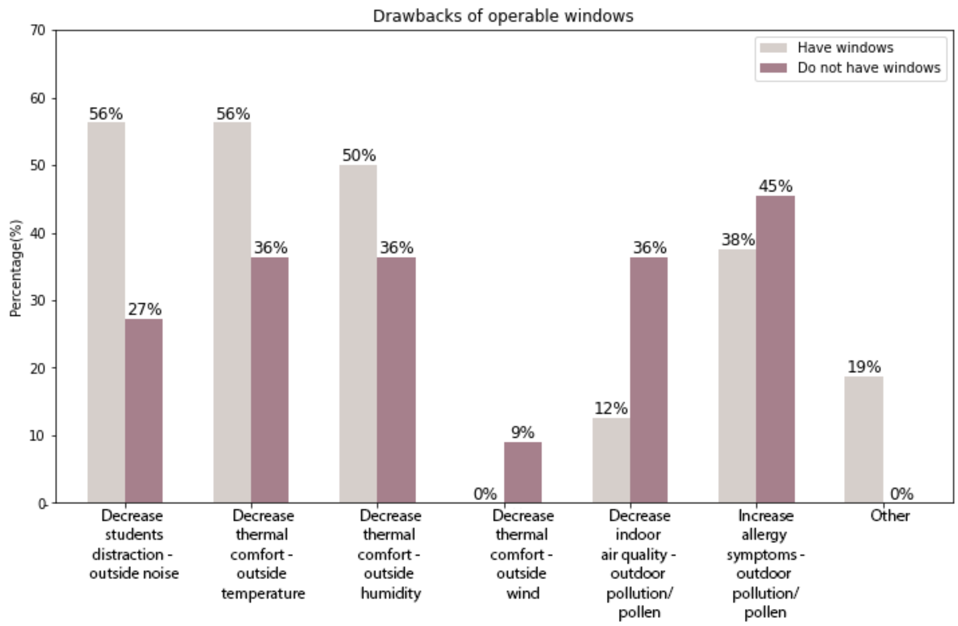

Figure 3.12: Drawbacks of operable windows

A sample of the open-ended survey and interview questions about the benefits and drawbacks of operable windows in classrooms from teachers' and engineers' perspectives are reviewed below. For the sake of the length of the paper, each category only has one or two examples, though the themes are consistent throughout all responses. The results are similar to the close-ended survey responses discussed previously, but also include other benefits and drawbacks.

Benefits:

- Thermal Comfort:

  P#5: *"... in the winter, the heat was just so stifling because it was blasting, I would open my window just to have some of that cold winter air come in to cool off the room a little bit…."*

  P#6: *"I've opened [operable windows] year-round, depending on the weather. We actually have a heated floor ... where it actually got warm, so I opened [the window] because it was uncomfortable because [the floor] was doing such a good job, heating the room."*

- Indoor Air Quality:

  P#3: *"[The operable window] is helpful …. with odor, at times like having the fresh air. I think I like the breeze, so if you are able to get the cross breeze, that's also beneficial..."*

  P#5: *"...the window…is the fresh air because our building, especially my wing, is old ... and so it is not the greatest as far as air-wise…."*

- Connection to Nature:

  P#6: *"...I would open [operable windows] in the morning. So, maybe 9:45 to 10:45, and then in the afternoon from 1:30 to 2:30. And then the kids enjoy the sounds and the sites through the screen, so that's really nice..."*

- Health and Safety:

  P#2: *"...I would have felt a lot safer teaching, knowing that there was airflow and air circulation in my space [through operable windows] …."*

  P#5: *"....it drives me crazy, as we have a girls' bathroom in our hallway, and there are windows in that bathroom, but they have locked them ... And I understand, I am* *assuming for safety. But if we needed to get out for whatever reason, you can't. I mean, the kids would be trapped in that bathroom, and it just makes me crazy…."*

- Students' Learning Performance

  P#4: *"...If I had windows, I wouldn't have to have the kids go outside [to record music], … because I cannot have them using the recorder in my classroom. They have to have more airways…."*

Drawbacks:

- Health and Safety:

  P#1: *"[I don't prefer operable windows] probably because I'm upstairs and you can have the kids jumping out …."*

  P#3: *"So I think the challenge is if we had a window that opened, I have students who are a flight risk and so having the two doors pose a problem…."*

  P#6: *"...I do have some kids with some allergies … so the times that we did open it, seemed to have kids who had some breathing issues because of their own stuff."*

- Security:

  P#2: *"...Security definitely … The area that we're in, you get a lot of people walking by, just going - a bus stop nearby. I had a random old guy knock on my window and ask me to come in because he had to pee, … and I'm like teaching little kids in here, no, sorry, I'm not letting you in. So, I think security is a big issue…."*

  P#7: *"...To me, the legitimate security risk is if [operable windows] don't get closed, leaving them open overnight …."*

- Animals and insects

  P#1: *"I experienced that before, lizards and snakes. I've had that just crawling [into the classrooms through operable windows]."*

  P#5: *"... I had a bird fly in [the classroom] last year. That is exciting. And I asked if I could put a screen ... and they said no because it's the emergency .... we've had birds, and wasps ..."*

- Indoor Air Quality:

  P#7: *".... Certainly, there are areas where the fresh air is not healthy, and then we wouldn't necessarily want to just bring in the fresh air, ... if you have the school next to the highway, and lots of trucks are going by, you don't necessarily want to breathe that in unfiltered...."*

- Students' Performance:

  P#2: *"...I guess, noise ... So, me being on [name of the road], if I had an open window, you might hear the traffic all day. So, I don't know if I could use it anyway, with all that noise ...."*

- HVAC Maintenance:

  P#7: *"...So we have these increasingly sophisticated systems, that whether it's taking CO2 readings, and humidity, and temperature, and adjusting based on time, based on occupancy and all those things, and then you throw open a window, and it throws that all off-balance...."*

Fans

The results around fans in classrooms show that teachers with fans mainly used them to improve IAQ (100%), decrease the exposure to COVID-19 (80%), and improve thermal comfort

(60%) during COVID-19 (Figure 3.13). These numbers are noticeably different than those before COVID-19, which might be result of bot having fans before COVID-19 (40% of teachers responded “Not Applicable” for using fans before COVD-19). Similarly ranked, the results around using fans for teachers currently without fans show that most teachers would like to use fans to improve thermal comfort (77%), followed by improving IAQ (23%), decreasing the risk of exposure to COVID-19 (18%), and improving students’ performance (14%) in their classrooms (Figure 3.14). The differences in results between the perspectives of teachers with fans and those without fans are noticeable. To clarify these differences in the survey responses, teachers were asked a similar question in the interviews. Responses indicate that teachers mainly prefer to have fans circulate air in the classroom, which increases the breeze and feels more thermally comfortable. Thus, fans are the primary preferred interaction for teachers to improve thermal comfort in the classrooms.

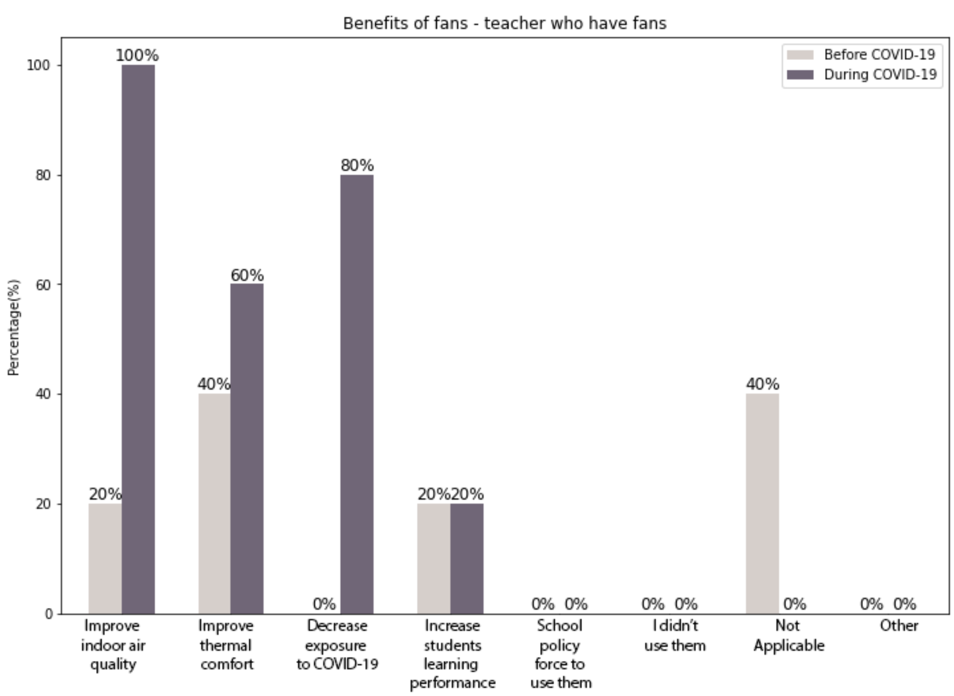

Figure 3.13: Benefits of fans before and during COVID-19 - teachers with fans

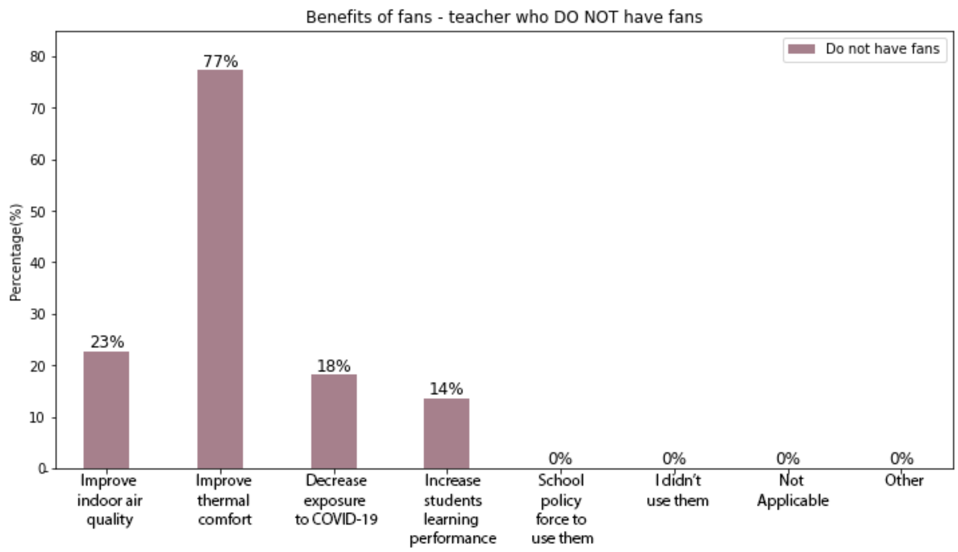

Figure 3.14: Benefits of fans before and during COVID-19 - teachers without fans

Responses from questions about drawbacks of fans in classrooms show that all teachers with fans in their classrooms always use them; of these, only one teacher mentioned disadvantages such as fan noise, dust, and breeze (Figure 3.15). Also, 55% of teachers without fans feel they would not use fans because of fan noise, followed by concerns of dust on the fan (45%) and the fan breeze (27%) (Figure 3.15).

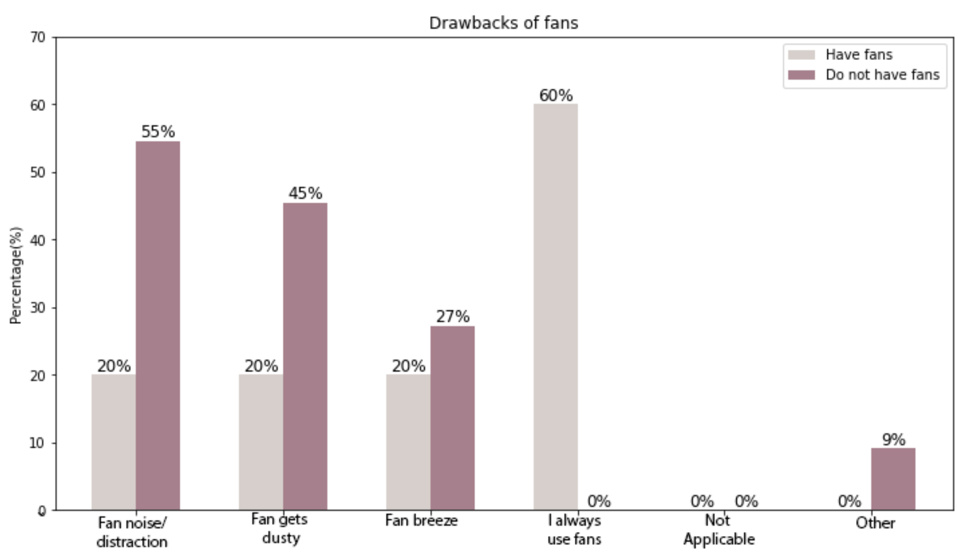

Figure 3.15: Drawbacks of fans

Open-ended survey and interview questions addressed the benefits and drawbacks of fans in classrooms from both teachers' and engineers' perspectives. Only one or two examples are shared for each category, but the themes are consistent among all responses. These results are similar to the results from close-ended survey questions discussed previously, but also include additional benefits and drawbacks.

Benefits:

- Thermal Comfort:

  P#4: *".... ceiling fans would allow an environment where students are not worrying about the thermal temperature of the room, pertaining to when it gets closer to hotter months, as well as being able to be more focused...."*

- Health and Safety:

  P#2: *"...I think just in the day and age of covid knowing that there's air circulation gives you peace of mind."*

Drawbacks:

- Thermal Comfort:

  P#6: *"...The drawbacks are you can have kids with sensory issues where if they feel it blowing on them that might make them feel very uncomfortable, and maybe not be able to function well in the classroom if they feel that on their skin."*

- Health and Safety:

  P#1: *"...I guess the downside could be again if a kid got their finger in it.... and ... if you have a kid with allergies, it's throwing dust around...."*

- Aesthetics:

  P#2: *"...I think it could be an eyesore. It's kind of tacky just to have fans sitting around in each room."*

  P#8: *"...aesthetically, I don't think [fans are] on a lot of people's minds for design...."*

- Student Performance:

  Teacher in School C (survey open-ended question): *"[A fan] creates a lot of white noise, limiting hearing access for hearing impaired students and staff and potentially causing sensory overload for ADHD, Autistic, anxious, and other high sensitivity students/staff."*

  P#4: *".... A box fan will lead to more disruption, and it only blows in one direction. The sound from it would be a little bit distracting while we were going to have our lessons...."*

Controllable Thermostat

Interviews addressed the benefits and drawbacks of controllable thermostats with the teachers and engineers. Most teachers indicated that they would like to control the thermostat to improve thermal comfort in their classrooms. However, engineers believe see challenges for giving teachers complete control over the thermostat such as increases in HVAC loads and decreases in systems efficiencies. However, they also see benefits to increased control including reducing maintenance calls to change the temperature. Both engineers believe that giving a certain level of temperature control to teachers could be beneficial in reducing maintenance calls. The drawbacks of giving this control over thermostats include a decrease in HVAC performance and an increase in energy consumption, which could cause financial and environmental issues. Teachers and engineers had similar thoughts to share about the benefits and drawbacks of a controllable thermostat.

Benefits

P#2: *"... I would prefer [to control my thermostat]. Just to have that ownership. I would feel more comfortable in case I had to change it. If I came in and it was too hot or too cold, or students are doing something very strenuous, I could make it a little cooler, or if we are doing something slow and relaxing, I could make it a little warmer, so the students are not cold. Depending on what I am teaching, having control over the temperature could help."*

P#4: *"If I were able to have a thermostat in my room, it would help with the ease of being able to fluctuate the temperature so that when there are moments when we're not moving around so much, and it is full, I will be able to move it up."*

P#7: *"...with a level of control [of the thermostat to teachers], it reduces maintenance calls. Maintenance folks can focus more of their time on bigger issues of preventative maintenance, in particular. Instead of going into a classroom and shooting the little laser and being like, oh yeah, it's hot, it's cold…."*

Drawbacks

P#7: *"...the disadvantages really come down to two things, one is general energy use. There's not a tight set point built into the thermostat. It could bring it down to 65 degrees, and it could stay there …. and it has huge, huge, huge financial and environmental implications for that massive increase of energy use, pulling it up to 80, dropping it to 65. And then the other is that it could also put a strain on the systems, depending on what type of HVAC system is in place. If one room is calling for 65, and the room next to its calling for 75 or 80… it can screw around with the system. And just even further, it increases energy and environmental impact, as well as stress on the equipment..."*

P#8: *"...what we found is ... sometimes students break them. They'll stick their pencils into them. Sometimes, it'll be too cold in a room, and if there's a thermostat present, the occupants will put the thermostat to 85 degrees to try to get it as warm as possible. And they'll notice that hey, it doesn't actually go to 85 .... It's really more of a placebo effect, to offer a button that they can push that says, make it cooler, make it hotter..."*

Shading

Window shading was mentioned in the open-ended survey questions as a way for teachers to improve thermal comfort in the classrooms. To gain more insight, teachers were asked in interviews about the benefits and drawbacks of shading. Main benefits noted include improving safety and security for lockdown drills, students' performance (control glare and distraction), and letting children sleep at nap times. The main drawbacks were related to shade cleanliness and how they open/close, which might negatively impact the safety and security of both teachers and students.

Benefits:

- Student mental health:

  P#2: *"...sometimes we open them to let in sunlight and close them if there's a bad storm or something, so the kids aren't freaking out. It's really nice to have the ability to open and close them yourself....."*

  P#6: *".... the kids need to take a nap, and it's very bright here during the day, so I do have one that's on a tension rod that I put up and down all the time. So that the kids can have a dark environment to sleep in because it's very important for our students to get enough sleep, and they can't do it with all of the bright light...."*

- Student performance:

  P#3: *"...the blinds are definitely helpful with controlling the sunlight at different points of the day. Also helping to redirect students' attention. If we have a quiz or something like that, [we can] close the blinds so that they can focus more on the work and not on what's going on outside."*

  P#5: *"... our kids are all on computers [and] depending on where they sit, where the sun would shine on their computer, and they couldn't see, so then I'd have to close a blind for that. But, unless they make a comment about not being able to see something or making them hot, we tend to leave them open...."*

- Student safety:

  P#5: *".... Ideally, I have them all open.... pre-covid, because if we ever had a lockdown drill, ... all of the blinds had to be closed. So that people can't see our windows .... "*

Drawbacks:

- Not easy to open/close and maintain

  P#1: *"Sometimes that particular kind [horizontal blind] can get tangled, or maybe like one side of the blind is going up or down, and the other one isn't ...."*

  P#4: *".... the [horizontal] blinds that I have, you can obviously draw them all the way up, and you can just bring them all the way down, but those blinds are really tricky, and there's [always] something wrong with them...."*

  P#5: *".... the first time I was at that school, and we had one [lockdown drill], [I was] trying to close all of them [blinds] and get it right to hide was just a lot. And I was like, I don't know what I'm going to do.... "*

- Student safety

  P#1: *“.... if you have small children, they can get strangled with the long traditional rope.... there’s a warning on all blinds that this is a hazard for children, keep your eyes on them, ...but we haven't had any incidences....”*

  P#4: *“... I don't personally like them [horizontal blind], because to me they're a threat to the safety of me and my students ... because if I needed to get those blinds back down, they are so messed up that it takes me about two, three minutes.... I don't personally prefer them [horizontal blind] ... because I can't be like to an active shooter: give me a second to put the blinds down. I don’t have that kind of time.”*

- Cleaning practices

  P#5: *“They're not clean. Ideally, the custodians would clean them, but they don't for many reasons, and so they're just dusty, and they're gross....”*

Discussion

This paper aims to understand (1) how teachers interact with interventions in their classrooms to improve thermal comfort in elementary schools in the United States before and during COVID-19, (2) how school buildings and policies support or limit those behaviors, and (3) benefits and drawbacks of identified interactions from teachers’ and engineers’ perspectives. This paper aims to provide a comprehensive understanding for school stakeholders of behaviors to improve thermal comfort in the classrooms and their holistic impact on students, teachers, and buildings. Part of an exploratory case study on behaviors to improve thermal comfort and IAQ in elementary schools in the United States, the study includes surveys with teachers and interviews with teachers and engineers in charge of HVAC systems in schools. Twenty-seven teachers participated in an online survey, and eight participants (six teachers and two engineers) were interviewed. This paper only includes data related to behaviors around improving thermal comfort in classrooms.

The results of the survey show that almost all teachers with some control over their classrooms like or somewhat like having these controls, including opening/closing windows, turning on/off the fans, and switching the thermostat temperature. Also, most teachers wished or somewhat wished to have control over their classrooms. The survey results also show that most teachers do feel thermally comfortable in their classrooms in all four seasons. However, more teachers feel comfortable in the fall and spring compared to summer and winter. Also, results also indicate that more participants feel uncomfortably cold/cool in their classrooms compared to uncomfortably hot/warm. Some interviewees also mentioned feeling cold in their classrooms more than hot, which supports survey results.

To support understanding teacher behaviors to improve thermal comfort in their classrooms before and during COVID-19, teachers were asked about their comfort-related behaviors in both surveys and interviews. Results show that using operable windows and shading devices are the most used behaviors of teachers to improve their thermal comfort when feeling hot or cold, both before and during the pandemic. Some survey respondents also mentioned other behaviors such as turning on/off the fans and switching thermostats, respectively. Teachers mentioned other personal-level behaviors to improve thermal comfort in their classrooms when students and teachers feel hot or cold in interviews and open-ended survey questions, including (1) wearing a jacket or blanket, or calling administration to adjust the temperature when cold, and (2) offering ice packs, taking off layers (i.e., sweater), wearing fewer clothes, or calling administration to adjust the temperature if hot.

Interviews queried the teachers about the impact of being thermally uncomfortable on their own performance and on student performance. Results aligned with the literature (Wargocki and Wyon, 2007; 2006; Shendell et al., 2004; Haverinen-Shaughnessy et al., 2011; Dias et al., 2011), illustrating that most teachers felt that being thermally uncomfortable negatively impacts student performance. Being thermally uncomfortable could make students sit, refuse to participate in classroom activities, not pay attention, or fall asleep. Also, one teacher mentioned personal health issues and how being cold in the classroom causes pain, preventing her from performing as desired.

To comprehensively understand the preferred behaviors to improve their thermal comfort, teachers were asked what they would do to improve thermal comfort in their classroom if they had all possible interventions at their disposal. All interviewed teachers indicated that they would prefer to adjust the thermostat first if they felt cold. However, a variety of preferences to improve thermal comfort when feeling hot were given. For example, some teachers would open windows first and then turn on the fans, and some would adjust the temperature of the thermostat first and then open windows. All teachers mentioned building-level interaction in their classrooms to improve thermal comfort, including using operable windows, window shadings, fans, and adjusting the temperature thermostat.

Since all behaviors come with benefits and drawbacks, it is essential to have a holistic and comprehensive understanding of the pros and cons of each behavior to build suggestions. To understand the breadth of how users can effectively utilize these behaviors in schools, interviews also included engineers in charge of HVAC systems, in addition to the teachers, to establish pros and cons (Table *3.3*).

Table 3.3: Benefits and drawbacks of comfort-related building interactions

	Benefits	Drawbacks
Operable windows	● Improve thermal comfort when it is hot ● Improve indoor air quality ○ Remove odor ○ Increase fresh air ● Improve connection to nature ○ Smell the rain ○ Listen to birds ● Improve student performance ○ Students can stay in the classroom to do some activities with a window open rather than having to go out for them ● Improve health and safety ○ COVID-19 ○ Emergency exits	● Decrease indoor air quality ○ Outdoor pollution/pollen ● Decrease student performance ○ Traffic noise and distraction ● Decrease HVAC performance ○ Unexpected load on the system ● Decrease health and safety ○ Students fall and injure themselves ○ Allergies (outdoor pollution/pollen) ● Decrease security ○ Shooting and violence ○ Forget to close them ● Cause animals and bugs crawl in the classroom
Window shading	● Improve student performance ○ Close in exams to decrease distraction ○ Close when they feel hot ○ Open when need more daylight/close them when there is a glare ● Improve student mental/physical health ○ Close them in a bad storm - students won't freak out ○ Close them when students' need to take a nap ● Improve student safety ○ Close in shooting drills	● The stings can get tangled and not perform well. ● Small kids get strangled with a long rope. ● It is hard to close/open the blinds, and it is a safety and security hazard when they need to be closed in case of emergency. ● Decrease indoor air quality: blinds get dusty, and no one cleans them frequently.

Table 3.3 (continued): Benefits and drawbacks of comfort-related building interactions

Fans	● Improve thermal comfort ○ Increase the breeze when it is hot ● Improve health and safety ○ Air circulation - COVID-19	● Decrease thermal comfort ○ Kids with sensory issues ● Decrease health and safety ○ Kids get hurt ○ Allergies - fan dust ● Interfere with aesthetics ● Decrease student performance ○ Fan noise - distraction ○ Fan breeze - make papers fly ● Decrease indoor air quality ○ Fan gets dusty
Controllable thermostat	Improve teacher control ● Adjust temperature based on the activities and number of students	● Decrease HVAC performance and efficiency ● Put an unexpected burden on the HVAC ● Increase energy use ● Cause financial and environmental issues

To effectively use each of the identified comfort-related behaviors, different stakeholders play an essential role in enhancing the benefits while also mitigating drawbacks. To this end, strategies for various stakeholders to design, implement and maintain building elements to improve thermal comfort while mitigating their weaknesses have been identified (Table 3.4). The benefits and drawbacks of the four preferred behaviors documented in the Results section - operable windows, shading, fans, and a controllable thermostat – provide the evidence for these suggestions.

As an exploratory case study, the goal of this study is to grow foundational knowledge and suggest essential areas to explore in future studies. Since the proposed strategies are based on an exploratory study with a low response rate, it is essential to expand this study to a more significant number of participants including different stakeholders. An expanded participant pool would help to solidify a holistic view of the pros and cons of comfort-related behaviors in classrooms. Additional participants would also provide robust information to suggest more practical and actionable recommendations to mitigate drawbacks and enhance benefits of these strategies holistically. Including different stakeholders in future studies will (1) improve general awareness about roles in improving thermal comfort in schools, (2) increase awareness about other stakeholders' needs and perspectives, and (3) provide actionable and practical suggestions to mitigate the drawbacks of identified behaviors and improve benefits. Also, it is essential to be clear about the different building elements being addressed in both surveys and interviews. For example, in this study, survey participants were asked about the benefits and drawbacks of fans without mentioning the specific type of fans (i.e., ceiling fan, desk fan, box fan, window fan). This general approach caused scattered responses; asking about specific types of fans would have provided more analyzable data.

This paper emphasizes the importance of including both qualitative and quantitative methods in future research to comprehensively understand situations and potential solutions in classrooms. Recommended data collection strategies include surveys, interviews, focus groups, and brainstorming sessions with stakeholders such as architects, school administrators, mechanical engineers, teachers, custodians, software engineers, UX designers, and students.

Table 3.4: Strategies for improving thermal comfort in classrooms

	Stakeholder	Strategies
Operable Windows	Window manufacturer	Design and manufacture windows that (1) are customizable based on the users' needs, (2) operate easily, (3) lock securely, (4) include screens, (5) clean and maintain easily.
	Software engineers/ UX designers	Design a software/tool to (1) suggest opening/closing windows based on indoor and outdoor conditions, and (2) remind teachers to close windows when leaving.
	Urban Planners	When zoning, site schools far from highways to reduce possible traffic disturbance.

Table 3.4 (continued): Strategies for improving thermal comfort in classrooms

	Architects	(1) Locate classrooms on a side with less disturbing noise; (2) Provide cross ventilation by installing two operable windows (preferably on the opposite of the space); (3) Design classroom adjacent to single loaded corridor to provide adequate cross ventilation through two windows in the opposite sides of the classrooms, (4) Locate windows considering daylight, safety (emergency exit, kids falling) and security (not letting people in); (5) Install lockable, easy to operate and clean windows with a screen to prevent animals and bugs; (6) Provide a tool to suggest opening/closing windows and trigger a reminder to close them when leaving the classroom; and (7) Educate teachers on how to use their classrooms to improve thermal comfort while mitigating potential drawbacks of their behaviors.
	HVAC/ Mechanical Engineers	(1) Provide sensors or indicators to let teachers know appropriate times to open/close windows and remind teachers to close windows when leaving; (2) Consider window status (open/close) when designing an HVAC system; (3) Educate teachers on how to use their classrooms to improve thermal comfort while mitigating potential drawbacks on HVAC performance.
	School Administrator	Provide training sessions for teachers about the benefits and drawbacks of operable windows and how to use them effectively.
	Teachers	(1) Find a way to remember to close and lock the windows when leaving the classroom; (2) Consider the holistic impact of opening/closing windows on the students, themselves, and building performance; (3) Actively attend training sessions to learn about their impact on the classrooms and students.
	Students	Learn how to interact with spaces to improve thermal comfort.
Fans	Architects	(1) Install a fan along with operable windows to help providing adequate cross ventilation, (2) Provide a child-safe box fan; (3) Install a less noisy fan (all types); (4) Provide fans with different levels of speed (all types); (5) Provide automated fans to reduce the chance of teachers forgetting to turn off the fans in their departure; (6) If providing a ceiling fan, locate it high enough so that papers will not fly about in the classroom; (7) Educate teachers and students about when to use fans to improve thermal comfort while mitigating potential drawbacks.
	HVAC/ Mechanical Engineers	Educate teachers on using their classrooms to improve thermal comfort while mitigating potential drawbacks of their behaviors on HVAC performance.
	Teachers	Actively attend training sessions to learn about their impact on classrooms and students.
	Custodians	Clean fans frequently and remove dust.

Table 3.4 (continued): Strategies for improving thermal comfort in classrooms

Controllable thermostat	HVAC/ Mechanical Engineers	(1) Give teachers limited control to adjust the thermostat temperature within a specific range, and (2) educate teachers on what to expect when changing the thermostat temperature and when to call the maintenance.
	Teachers	Attend training sessions that engineers hold at their school to learn what should be expected when changing the thermostat temperature.
Shading	Architects	(1) Install external shading to reduce the glare and harmful sun exposure; which can also be used as protection against hurricane in some part of the country, and could be designed to have some substantial protect against bullets, (2) Install interior shading which easily functions properly and does not require significant maintenance; (3) Use automated shadings (interior and exterior) and avoid shading with long ropes; (4) Consider time required for teachers to open/close shadings in case of emergency.
	Custodians	Clean the shadings frequently and remove dust.

Conclusion

Schools are the second most prevalent environment in children's lives after their homes (Baki-Biro et al., 2012; Mendell et al., 2013), a fact that establishes the importance of school environments in students' learning performance, health, and comfort (Abramson et al., 2006; Annesi-Maesano et al., 2013; Mendes et al., 2014; Almeida et al., 2016). Comfort is understood to be an important parameter in improving students' learning performance (Wargocki and Wyon, 2007). Thermal comfort has the highest impact on this issue of human comfort (Frontczak and Wargocki, 2011). Studies show that uncomfortable thermal environments negatively affect student learning performance (Wargocki and Wyon, 2006; 2007; Shendell et al., 2004; Haverinen-Shaughnessy et al., 2011; Dias et al., 2011). Due to individual preference, people might feel different comfort levels in the same physical, thermal conditions (ANSI/ASHRAE Standard 55, 2017), leading to various behaviors focused on improving thermal comfort in similar spaces. International studies primarily utilize two models to explain thermal comfort in spaces: (1) the rational model and (2) the adaptive model (Martinez-Molina et al., 2017). The adaptive model is more realistic, especially in naturally ventilated spaces, considering occupant behaviors to improve thermal comfort in buildings. Liang et al. (2012) clarify that the adaptive model has mainly been studied in office buildings with adult populations. There is a gap in studies on understanding adaptive behaviors in school buildings to improve thermal comfort.

Teachers and staff have the autonomy to interact with classrooms to improve thermal comfort, influenced by different decision-making factors (Balvedi et al., 2018). To truly improve both thermal comfort and energy efficiency in schools, it is essential to have a comprehensive understanding of how teachers prefer to improve thermal comfort and the factors behind their decisions. Also, after March 2020, when COVID-19 hit the world and impacted fundamental aspects of people's lives including health, economy, and education, people became more aware of their built environments. Thus, preferred behaviors might have changed during the pandemic. While a few studies focus on behaviors in light of COVID-19, there is a lack of studies on K-12 schools and preferred behaviors.

Moreover, since each behavior likely comes with pros and cons, it is essential to have a holistic understanding of teachers' preferred behaviors to improve thermal comfort in an effort to mitigate drawbacks while enhancing benefits. Thus, this paper focuses on teachers' preferred interactions with their classrooms to improve thermal comfort before and during COVID-19, as well as the benefits and drawbacks of those behaviors. Since different stakeholders influence building elements and interactions, this study suggests recommendations for various stakeholders to enhance the benefits of thermal comfort behaviors while mitigating their drawbacks.

This study is a part of an exploratory case study to better understand teachers' behaviors to improve thermal comfort and IAQ in elementary schools in the United States. Four elementary schools - three in North Carolina and one in Illinois - participated in this research. The methods used in this study are (1) surveys with teachers and (2) interviews with teachers and engineers in charge of HVAC systems. Twenty-seven survey respondents and eight interviewees participated in this study. Due to COVID-19, the survey response rate and interview participation was lower than expected. Thus, the results in this paper provide a foundation for future research to learn more about comfort-related behaviors, their pros and cons, and how to improve the effectiveness of those behaviors holistically.

This study shows that teachers like having a level of control over their classroom environment, which aligns with existing literature (Brager et al., 2004; Mishra and Ramgopal, 2015; Buonocore et al., 2019; Jindal, 2018). Teachers prefer to use operable windows, shading devices, fans, the thermostat, while also initiating personal-level behaviors such as drinking water, offering ice packs, and wearing/taking off the jacket to improve thermal comfort in their classrooms. Teachers also mentioned how being thermally uncomfortable negatively impacts students' performance, supporting existing literature (Wargocki and Wyon, 2007; 2006; Shendell et al. 2004; Haverinen-Shaughnessy et al., 2011; Dias et al., 2011).

In surveys and interviews, participants addressed the benefits and drawbacks of each comfort-related building element (operable windows, fans, controllable thermostat, shading). The results show that operable windows could negatively or positively impact indoor air quality, health and safety, and student performance, highlighting the importance of ease of quick operation. Participants also believe that operable windows would improve thermal comfort and connection to nature, though they might decrease HVAC performance, security, and letting animals and bugs get inside the classrooms. Results also indicate that participants believe fans could both improve or interfere with thermal comfort and health and safety, depending on the type, location, and operation. Participants also mentioned other drawbacks for fans, such as not being aesthetically pleasing, decreasing student performance, and indoor air quality.

Moreover, almost all teachers believed it would be beneficial to control their thermostats; however, engineers believed that giving teachers control would decrease HVAC performance and increase energy consumption, leading to financial and environmental issues. Finally, participants believe that shadings might improve students' performance, mental and physical health, and health and safety. However, at the same time, shading might negatively impact indoor air quality and safety while having issues with how they operate (hard to open/close).

This study suggested recommendations for different stakeholders to mitigate drawbacks identified by participants while enhancing the benefits of each strategy (Table 4). This paper provides foundational knowledge on preferred behaviors of teachers to improve thermal comfort and addresses the pros and cons of these behaviors. Due to limited participants, it is suggested to expand the scale of this study to include more participants from different school districts in different climate regions to have a more comprehensive understanding of preferred behaviors. Also, this study encourages interdisciplinary mixed methods studies where various stakeholders participate through qualitative and quantitative methods.

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APPENDICES

Appendix A- Holistic Synthesis of Leading Agencies' Architectural Guidelines

Agencies	Guideline Title	Year	Building Types									Recommendations									
			School	Office	Retail/Commercial	Residential	University	Religious Spaces	Healthcare Facilities	Senior Living Facilities	Restaurant	Operable Windows	Fans	Outdoor Spaces	Touchless Fixtures	Layout to Maintain Physical Distancing	Physical Barriers	Entrance/Elevator/Hallways	Restrooms	Acoustic Treatments	Natural Lighting
CDC	Operating schools during COVID-19: CDC's considerations	2021	x									x	x			x		x			
	COVID-19 employer information for office buildings	2021		x								x	x	x	x	x	x				
	Guidance for businesses and employers responding to COVID-19	2021		x								x	x			x	x				
	How do I set up my classroom? A quick guide for teachers	2021	x									x	x			x	x				
	Ventilation in buildings	2021										x	x								
	CDC updates operational strategy for K-12 schools to reflect new evidence on physical distance in classrooms	2021	x													x					
WHO	Getting your workplace ready for COVID-19	2020		x								x									
	Checklist to support schools re-opening and preparation for COVID-19 resurgences or similar public health crisis	2020	x									x				x					
	Roadmap to improve and ensure good indoor ventilation in the context of COVID-19	2021	x	x	x	x	x	x	x			x	x	x							

Appendix A (continued) - Holistic Synthesis of Leading Agencies' Architectural Guidelines

Agencies	Guideline Title	Year	Building Types											Recommendations							
			School	Office	Retail/Commercial	Residential	University	Religious Spaces	Healthcare Facilities	Senior Living Facilities	Restaurant	Operable Windows	Fans	Outdoor Spaces	Touchless Fixtures	Layout to Maintain Physical Distancing	Physical Barriers	Entrance/Elevator/Hallways	Restrooms	Acoustic Treatments	Natural Lighting
AIA	Reopening America: Strategies for safer offices	2020		x								x		x	x	x	x	x	x	x	
	Re-occupancy assessment tool v. 3.0	2020	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x
	Reopening America: Strategies for safer schools	2020	x									x		x	x	x	x	x	x	x	x
	Reopening America: Strategies for safer senior living communities	2020								x		x		x	x	x		x	x	x	
	Reopening America: Strategies for safer multifamily housing	2020				x								x	x	x		x	x		
	Reopening America: Strategies for safer retail	2020			x									x	x	x	x	x			

Appendix B - Detailed Synthesis of Architectural Recommendations Suggested by CDC, WHO, and AIA

Main Categories	Sub-Categories		Recommendations	Agencies			Building Types							
				CDC	AIA	WHO	School	Office	Multifamily Housing	Restaurants	Senior Living Facilities	Commercial Retail	Healthcare Facilities	Universities
Programming & Design	Interior	Entrance and Lobby Areas	Separate the entrance from the exit		x	x	x	x	x	x	x	x		
			Provide and identify multiple entrances during arrival and departures for different groups of people		x		x	x	x	x	x	x		
			Provide touchless entry		x		x	x	x	x	x	x		
			Provide recommended spots/locations to maintain 6 feet distancing in the building and its entry		x		x	x	x	x	x	x		
			Provide space in the entry queuing to maintain a minimum of 6 feet, and minimize exposure to sun, wind, precipitation		x		x			x		x		
			Provide one-way direction in hallways, entrances, and exit points		x		x	x	x	x	x	x		
		Elevator	Program elevators to pick only one person upon one floor and go to only one floor to drop the person.		x			x						
			Allow a limited number of people in the elevator at one time.		x			x						
			Change the elevator controls to operate with voice or phone.		x			x						
		Public Restrooms	Install touchless toilet flushing, toilet lid closure, faucets, soap dispensers, and paper towel dispensers		x		x	x		x	x	x		
			Install/provide toilet lids		x		x	x		x	x	x		
			Limit the access to restroom plumbing to provide at least 6 feet between individuals.		x		x	x		x	x	x		
			Provide barriers/floor marking to maintain physical distancing when queuing		x		x	x		x	x	x		
			Replace/provide restroom stalls from floor to ceiling with considering fire safety and ventilation		x		x	x		x	x	x		
			Eliminate doors in the restroom when possible, by providing a long entry to minimize the sightlines		x		x	x		x	x	x		
			Provide automatic door openers, hand-free door hardware, or proximity sensors		x		x	x		x	x	x		
		Healthcare	Install drive-thru and pick-up services windows		x			x		x		x		
			In aerosol-generating procedure (AGP) rooms, place an anteroom with double doors that won't open simultaneously or use a plastic door zip as a partition to create an anteroom.			x							x	
			Reducing the maximum number of people to meet the required standard for air ventilation			x							x	
		Other Spaces	Setting up different entrances for different classes		x		x							
			Increase the interior space for queuing		x		x	x	x	x	x	x		
			Provide at least 3 feet of physical distancing for both students and staff inside and outside of the classroom, where possible			x	x							
			Provide supervised quarantine area for symptomatic students		x		x							
			Using cafeterias, gymnasiums, and libraries as larger classroom spaces		x		x							

Appendix B (continued) - Detailed Synthesis of Architectural Recommendations Suggested by CDC, WHO, and AIA

Main Categories	Sub-Categories		Recommendations	Agencies: CDC	Agencies: AIA	Agencies: WHO	Building Types: School	Building Types: Office	Building Types: Multifamily Housing	Building Types: Restaurants	Building Types: Senior Living Facilities	Building Types: Commercial Retail	Building Types: Healthcare Facilities	Building Types: Universities
Programming & Design	Interior	Other Spaces	Eliminate coat closets and storage areas		x			x						
Programming & Design	Interior	Other Spaces	Provide more multifunctional spaces for the work/learning from home		x				x					
Programming & Design	Interior	Other Spaces	Expand building storage area to store supplies and PPEs for emergency needs		x				x					
Programming & Design	Interior	Other Spaces	Identify a designated space for visitation, with a direct access to outdoor		x						x			
Programming & Design	Exterior		Provide outdoor space and seating		x	x	x	x	x	x	x	x	x	x
Programming & Design	Exterior		Provide an outdoor area for the family visit		x		x				x			
Programming & Design	Exterior		Provide outdoor heating/cooling/shading for outdoor seating/activities		x		x	x	x	x	x			
Programming & Design	Exterior		Provide and encourage outdoor activities when appropriate		x	x	x							
Programming & Design	Exterior		Providing dispenser temporary work areas for outdoor working		x			x	x		x			
Programming & Design	Exterior		Provide space for garden and planting		x		x	x	x	x	x	x		
Programming & Design	Exterior		Provide a large balcony, patio, and porches with screens and louvers		x				x					
Programming & Design	Exterior		Provide the curbside pickup in the parking; Using parking lot as a waiting area		x					x				
airflow and ventilation	Window Operation		Windows should be opened for 15 minutes when entering the room esp. when the room was occupied by others beforehand.			x	x	x		x	x			x
airflow and ventilation	Window Operation		Providing cross-ventilation instead of single-sided ventilation in spaces except when the airflow is moving from a less clean area to a clean area			x	x	x	x				x	x
airflow and ventilation	Window Operation		Open windows and doors to increase fresh air when the outdoor weather condition allows in buildings with and without a mechanical ventilation system.	x	x	x	x	x	x	x	x	x		
airflow and ventilation	Window Operation		Do not open windows/doors if there are safety issues, i.e. risking falling and triggering asthma symptom	x	x	x	x	x	x	x	x	x		
airflow and ventilation	Window Operation		Enable/improve stack effects for ventilation			x	x	x				x	x	x
airflow and ventilation	Fans		Use fans to increase the effectiveness of open windows	x		x	x	x	x					x
airflow and ventilation	Fans		Use window-installable products to provide exhaust ventilation			x			x					
airflow and ventilation	Fans		Use a pedestal fan close to the window and facing it towards the window to enable ventilation			x	x	x					x	x
airflow and ventilation	Fans		Use child-safe fans to increase the effectiveness of operable windows	x			x							
airflow and ventilation	Fans		Use a window fan which is placed safely and securely in the window to exhaust room air outdoors, which helps draw the fresh air into the room through other open windows and doors without generating strong room air currents	x			x	x						
airflow and ventilation	Fans		If the room has fans, manage the airflow in a way that it does not blow from one person directly to others	x	x		x	x		x	x			

Appendix B (continued) - Detailed Synthesis of Architectural Recommendations Suggested by CDC, WHO, and AIA

Main Categories	Sub-Categories	Recommendations	Agencies			Building Types							
			CDC	AIA	WHO	School	Office	Multifamily Housing	Restaurants	Senior Living Facilities	Commercial Retail	Healthcare Facilities	Universities
	Furniture and Appliances	Provide easy to clean furniture		x		x	x	x	x	x	x		
		Provide Bluetooth credit only, hands-free and/or easy-to-clean vending machine		x		x	x	x	x	x	x		
		Utilize Internet of Thing (IoT) technology to reduce touchpoints		x		x	x	x	x	x	x		
		Provide a touchless door lock, turnstiles, timecards, valves, faucet, handwashing stations, hygiene stations, hand soap, hand towel, hand dryer and water fountain (water filling station),		x		x	x	x	x	x	x		
		Minimize use of high-touch and hard to clean equipment and furniture (i.e., rugs)		x				x		x			
		Turn desks to face in the same direction	x	x		x							
		Have students sit on only one side of the tables, spaced apart	x			x							
		Provide at least 6 feet between seating and desks when possible	x	x		x	x		x	x			
		Increase the space of seating and/or reduce density in dining and break rooms		x		x	x		x	x			
		Reduce the amounts of equipment's to provide more space			x	x	x	x	x	x	x		
		Remove the lockers in the corridors to widen the path		x		x							
		Provide physical barriers esp. in places where it is difficult to maintain 6 feet distance		x		x	x		x		x		
		Install clear plastics or sneeze guards as physical barriers		x		x	x	x	x	x	x		
		Use cubbies, shelf, and other classroom furniture as low barriers adjacent to students' desks and teacher's area		x		x							
		Provide temporary partitions or tall booths in dining areas		x		x	x		x	x			
		Provide temporary and movable partitions to divide large working spaces		x			x						
		Provide personal headsets instead of shared desk phones		x			x						
		Provide an extra monitor at workstations for video conferences		x			x						
		Provide required technology into the resident's room to enable virtual connection		x						x			
Acoustics and Lighting		Use motion sensor controls and phone-based application control for switching the lights		x							x		
		Use natural light when possible		x		x	x	x	x	x	x		
		Provide light bulb that simulates daylight to improve mental health when light is limited		x				x					
		Enhance acoustic treatments to make sure occupants can hear/be heard with masks		x		x	x	z	z	x	z		