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An Investigation into Energy and Cost of Strategies that can Mitigate risk of Covid-19 transmission

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Abstract

In order to systematically reduce the risk of SARS-CoV-2 infection in the indoor space, it is important to understand the building design strategies and air quality enhancement methods that are set to mitigate this threat. As the universities are resuming their pre-Covid in-person curriculums, this paper aims to introduce the different HVAC technologies used to mitigate the spread of Covid-19 in the university classrooms, in particular. Many of these technologies came to be as an outcome of the scientific interest in the enhancement of indoor environmental quality. Thus, it is important to understand where airborne pathogens fit in the overall scheme of indoor air health. Similarly, this paper sets to reimagine the architectural methods as the solutions to the problem of airborne transmission of diseases. Based on the urgency of the problem and the demand of the market, in this work, we discuss a summary of applicable technologies and strategies to combat airborne viruses, particularly Covid-19, in the ventilation systems and enclosed spaces. By presenting an overview of the problem and the solutions that integrate engineering controls, the design strategies and indoor air sanitization techniques aim to create healthier indoor environments. This paper aspires to move the research forward.

Keywords: *Architecture, Covid-19, Disinfection, Indoor air quality, Ventilation.*

1. Introduction

The emergence of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) has led to an unprecedented global outbreak in the recent years due to the coronavirus disease 2019 (Covid-19). The scientists studying the phenomenon refer to the virus as Coronavirus and related disease, Covid-19 [1]. The initial step in addressing the way the Covid-19 pandemic has affected the overall indoor environmental quality (IEQ) and indoor air health is to create an understanding of what it takes to have healthy air indoors, regardless of the pandemic. By doing so, the measures that are uniquely necessary for combating Covid-19 reveal themselves. The pre-pandemic health checklist consist of the elements like assessing the parameters involved in thermal comfort and indoor air quality to subjective analysis gathered from occupants post-occupation [2]. However, since the start of the Covid-19 outbreak, the urgency of re-considering and re-assessing all the elements that ensure a healthier indoor air quality before occupants are present has increased [3]. On the topic of airborne pathogens, it is important to note that the virus-infected particles can still be contagious while being suspended in the air for several hours [4]. Thus Corona Virus-related concerns must be addressed immediately in all the guiding protocols concerned with the health of the indoor environment [5].

Based on a research work, IEQ directly correlates with the comfort, productivity, efficiency, health, and overall satisfaction of the occupants [6]. In most literature, the IEQ factors are usually classified into the environmental and non-environmental factors. The environmental factors (e.g. thermal conditions, indoor air, lighting, and acoustics) can be assessed by the objective methods before the occupation of a built environment; these elements are similarly much easier to simulate or survey [7]. Yet the non-environmental factors such as furniture, ergonomics, privacy, circulation, and patterns of movement are significantly more difficult to

measure or survey post-occupation; however, they play a major role in the way pathogens are distributed and deactivated [8].
Thermal environment and air-quality of classrooms are known to have significant effects on the cognitive performance of the university student [9, 10]. Yang and Mak [11] have concluded that the acceptability of thermal environment is often the most important factor in the quality of indoor environment. Yet having acceptable thermal conditions and standard air quality has often been regarded as the base for healthy indoor environment requirements. As evident by the current pandemic, guaranteeing indoor air-health is challenging. Besides the aforementioned factors, additional elements like greenery play a significant role in the overall perceived environmental quality. Van den Bogerd et al. [12] have demonstrated that greenery (e.g. potted plants, green walls, vertical gardens) indoors result in consistently of the higher satisfaction rates among the students.
The harms of poor indoor air quality are known as "indoor diseases" [13]. Some of these immediate problems can be fixed by exiting the polluted area; however, in the case of the pre-existing health condition like asthma, diabetes or allergies, the unhealthy air, even in a short exposure, may aggravate their conditions [14, 15].
This paper reviews the methods of deactivating and eradicating viral pathogens that might also be effective on the Coronavirus. The hypothetical space in which these methods need to perform in is a university classroom. The measures are discussed in the context of other university buildings briefly as well; however, the majority of the discussion is focused on a standard 50 m_2 university classroom. Consequently, the factors that make the Covid-19 virus different from other viral air polluters are discussed, and how these factors correlate with one another is analyzed. Subsequently, the methods of detecting and eradicating the virus in indoor environments, ways that those methods can be integrated into the architecture, and possible solutions for a hypothetical university classroom that avoid exacerbating the spread of the virus are introduced. Finally, the strategies for improving the environmental quality status through architectural methods are presented.

2. Exploring parameters that effect indoor air quality

As mentioned earlier, the indoor air and thermal comfort parameters are heavily influential in the overall health of occupants to such an extent that several standards have been assigned to ensure the standard state of these parameters in the indoor environment. The routine practiced standards for indoor thermal and air quality control are ASHRAE [16], CEN [17], ISO and EPFEFIB [18]. The ISO and CEN standards go a step further and set limits for acoustic and lighting requirements. During the outbreak of Covid-19, the same organizations were tasked with revising and implementing new standards that hoped to reduce chances of contracting the virus. Among these, the most-cited sources are Guidance from World Health Organization [19], Guidance from Environmental Protection Agency (5), and Guidance from the Centers for Disease Control and Prevention [20].
In studies focused on the IAQ parameters and indoor environment health, humidity, temperature, carbon dioxide, radon, and particulate matters (PM0.5, PM1.0, PM2.5, PM5.0, and PM10) are the most featured indicators in assessing the indoor air quality. Among these, carbon dioxide is the most monitored parameter as an indicator of indoor air conditions. This is due to both the accessibility of CO_2 monitoring equipment and reliability of CO_2 as an indicator of proper air-exchange rate. Since in an indoor environment, like a university classroom, often the occupants are the main producers of CO_2 resulting in the concentration of CO_2 indoors being higher than outdoors [21]. The monitoring of temperature and relative humidity of the indoor environment often goes hand in hand for a more comprehensive assessment. Among the polluters of indoor air, the most prevalent ones measured are carbon monoxide (CO), PPMs, Radon, VOCs, and mold. Another parameter measured commonly to assess the health of indoor air, is the air exchange rate of the studied environment [22]. Global change and unprecedented high energy demands have led the building development sector to maximize energy-saving practices, practices like lowering air-exchange rates (ACH) that negatively impact the CO_2 concentrations in confined spaces [23] and with the outbreak of Covid-19, the commonly reduced ACH in ventilation systems has proven to be fatally dangerous [24]. With the climate-crisis still looming large, the urgent need for assessing the post-occupancy acceptability of the assigned air-exchange-rate has become more pronounced.

3. Understanding elements of Covid-19 outbreak

Viruses are considered as biological pathogens in the form of airborne particulate matter in IAQ studies [25]. Thus, for the purposes of indoor air health practices, Covid-19 virus can be categorized in a like manner. Preventing lungs and the respiratory system ailments has long been the main goal of indoor air quality standards. Even before the Covid-19 outbreak, these illnesses accounted for up to 3.4 million deaths annually, on a global scale [26]. More than 2 million of the fatalities can be traced back to fine particulate matter [27]. Respiratory droplets often have a diameter that exceeds 5-10 millimeters; thus, gravity pulls them down to the surface in any given building. The droplets that have a diameter less than 5 μm and can stay suspended in the air whilst traveling for several meters are called “droplet nuclei”, and account for most airborne illness transmittance (4). In fact, some studies have concluded that there is a positive correlation between air pollution and the concentration of PM in indoor air and transmission of Covid-19 since atmospheric particulate matter (PM) is a perfect vehicle for transporting Covid-19 viruses further than they would travel in clean air. Furthermore, air polluters are known to cause inflammatory reactions in lungs, and thus worsen the symptoms of those infected with Covid-19 [28].

3.1. Methods of detecting and eradicating virus in an indoor environment

The spread and transmission of the Covid-19 pathogens has a few key characteristics. Pathogens usually infiltrate the organisms through different transmission mechanisms: ingestion (via the fecal-oral route), inhalation, inoculation, contact, iatrogenic transmission, and coupling. The most common route of transmission in the case of Covid-19 pathogens is inhalation [28].

In the systematic attempts to control Covid-19 spread, several organizations have devised a method called hierarchy of controls. The hierarchy of actions devised by Occupational Safety and Health Administration of the United States [29] is heavily referenced as the baseline for the proper sequence of hazard control procedures. The hierarchy of controls is a system that arranges the effective methods of control, prevention, and eradication of a hazard such as SARS-CoV-2 (Covid-19) in order of success [30].

As depicted in figure 1, elimination is the first and most effective tool in the hazard control. In the workplaces, it often means removing and mitigating the possibility of hazard. In the case of Covid-19 outbreak, this method is translated into internetworking or teleworking.

Substitution refers to the act of replacing a given hazard with something less hazardous. «Administering a drug that interferes with the viruses’ ability to replicate once a person is infected is, in effect, making a more lethal virus into a less lethal one». This work is being administrated for Covid-19 but may take a long time to fully vaccinate the entire population and those who need it [31].

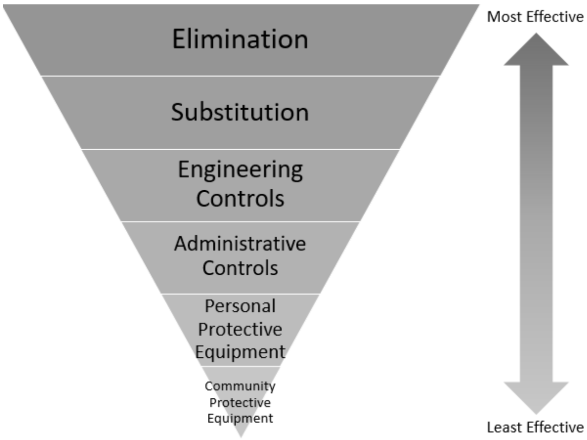

Figure 1. Hierarchy of control for Covid-19 spread.

Implementing the engineering controls in this case has meant isolating people from a hazardous possibility or placing a barrier between the occupants, for example, transparent vinyl partitions dividing open office spaces or shielding bank tellers from possible respiratory droplets breathed onto them by customers. Similarly, for the healthcare workers that need to directly work with infected people, providing a ventilation hood is another method of protection through the use of an engineering control [29].

Administrative controls mean demanding a change, often temporary, in the way people work or act, including policy or procedures implementations to reduce or minimize hazardous exposure; asking everyone to pay more attention to their personal hygiene, reducing the number of workers that need to be physically present in a workplace, in this case university offices, limiting the size of gatherings and asking people to keep 2 meters of distance between them at all times are examples of administrative controls. The problem with this course of action is that compliance is required for administrative controls to be successful, and human beings do not comply perfectly [31].

Personal Protective Equipment (PPE), e.g., masks, gloves, protective clothing, and constant sanitizing are the last barricade between an individual and Covid-19. Unsurprisingly, this method of control is the least effective form of hazard control. However, since it can be implemented quickly if the products are available, it can be used to ensure a minimum-level safety.

Since the proper methods of hazard control during the Covid-19 pandemic were introduced, it is evident that “indoor air quality control” and subsequent architectural solutions fall into the engineering control section of the hierarchy. All the construction solutions and HVAC modifications are implemented in order to minimize the transmission of airborne disease in indoor spaces.

4. Possible architectural or HVAC solutions that are more likely to be effective in mitigating spread of virus

Architects hope that the Covid-19 pandemic ushers in an era of healthier built environments. By maximizing the potential of attributes like light, airflow, greenery, spatial design, and the right building materials. The progress hopefully will include the constructors and building managers acknowledging the importance of following the guidelines in controlling the spread of disease. The designers should reintroduce the concept of healthy indoor environment as a requirement rather than a luxury.

The first objective is to integrate the built environment into the local climate. Through building orientation and siting, prioritizing natural forces like air-flow and light, in air circulation and disinfection as well as thermal control, a built environment can increase its potential without any additional construction expanses or mechanical maintenance [32]. In the next steps, providing each space with its proper HVAC units or vent and filtration can be a huge upgrade towards providing classrooms with a healthier environment.

However, there has to be clear scientific strategies adapted in order to reduce the transmission risk of Covid-19. These strategies need to be operational both in the low-tech spaces and the high-tech ones. One of the certifiable methods that can be utilized in reducing the transmission risks in built environments is upgrading the HVAC protocols and equipment. Even though the HVAC modifications can increase the operational costs and may not be applicable to all situations, for example, buildings that mostly rely on natural ventilation, they are one of the easiest construction methods to implement, and they have proven to be effective in reducing pathogens and improving indoor air health.

It is important to keep in mind that out of the methods listed below, none completely remove the viral airborne particles from an enclosed space, and thus it is best that several methods are utilized in conjunction to reduce the possibility of failure. The mitigation of Covid-19 particles in and indoor space depends on the ability to provide a clean fresh air to a space, and it is important to keep in mind that even then the possibility of contracting Covid-19 is related to the concept of a quantum, the amount of ingested virus by someone healthy before they become infected, and the duration in which the airborne virus may be active [33].

• Ventilation is a necessary and efficacious way of ensuring that the concentration of Covid-19 droplets is reduced. Increased ventilation can be achieved through increasing the air-exchange rate of an HVAC unit, increasing the fresh air-supply of a unit or opening a window in free-running systems. Based on the studies into removing pathogens from the air [34], [35] and studies on how these methods might fair in regards to the Covid-19 droplets [36], [37], the following diagram was produced:

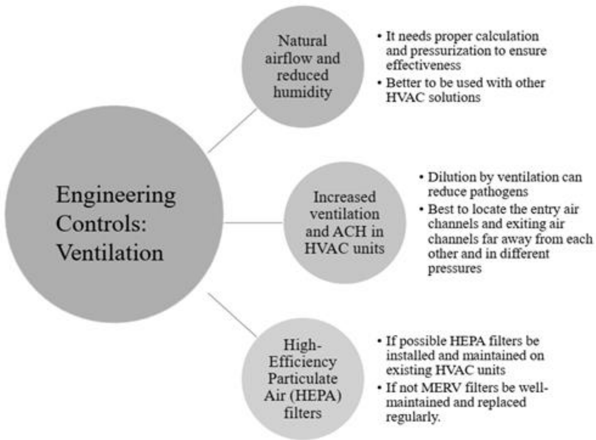

Figure 2. Engineering control measures regarding ventilation.

• As mentioned earlier, the Covid-19 droplets are regarded as aerosols, and like any other hazardous particle matter, can be removed from the air through a proper air filtration. Thus, a medium to highly efficient air-filter installed on an operating HVAC system can be monumentally advantageous to air purification.

• Air ionization can be effective in settling the virus carrying droplets on different surfaces; however, this method does not deactivate the virus, and has a downside of creating and diffusing ozone.

• The ultra-violet technology can be installed on either the HVAC systems or air-entries in order to inactivate the virus. Ultraviolet light in the C spectrum (100-280 nm) can successfully eliminate the microorganisms including bacteria, viruses, mold spores, mildew, and other pathogens, and thus might be effective in mitigating the spread of

Covid-19 though Ultra-Violet Germicidal Irradiation (UVGI) [38].

• Non-thermal plasma can be utilized to inactivate airborne pathogens; in the case of Covid-19, it can be introduced to indoor spaces in the form of a portable air sterilizing device [39]. However, the specialized laboratories necessary to determine its effectiveness on human viruses are too expensive, and that is holding the research back in this area [40].

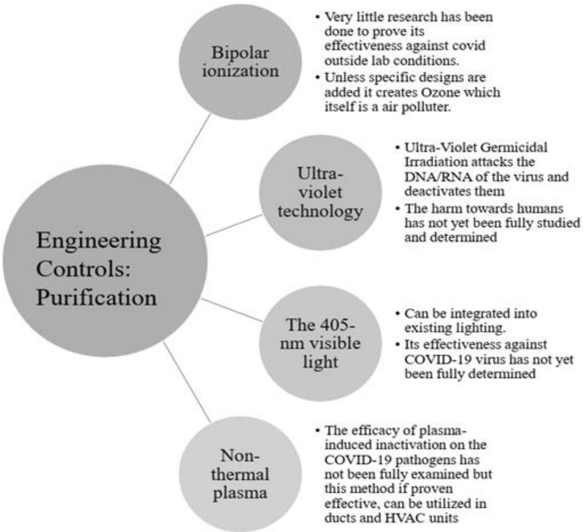

Figure 3. Engineering control measures in regard to purification.

5. Architectural measures of reducing Covid-19 risk for students on campus

Dorm rooms and classrooms can be the breeding-ground of many Covid-19 new cases due to being full of interacting students who spend a long time in close proximity in these spaces. In general, there are several methods of reducing the risk of Covid-19 spread in crowded living and working areas like dorms and classrooms. These methods range from low-tech approaches to high-tech renovations and re-designs. In low-tech measures, a university head or dorm management administration can:

- Re-arrange the furniture to avoid exposing the individuals on the same airflow "corridor"[41]. The risk of placing the individuals on the same airflow corridor is schematically depicted in figure 4.
- Design the sleeping/sitting arrangements in a way that reduces the chance of students breathing in each-others' direct expiration [42].
- Enact a decentralization of facilities. Providing students with smaller units of service such as diners, study halls, and community centers [43].
- If possible, limit the number of people allowed in a class room and assign seating arrangements with proper physical distancing in gathering spaces [44].
- Replace the WC hand dryers with disposable towels to reduce air turbulence.
- Provide students with the possibility of opening windows in buildings with HVAC systems that cannot filter or pull in outside air with windows that can open so that the exchange of fresh air can be increased upon demand or need.
- Keep the windows in buildings with central HVAC systems locked to reduce indoor temperature changes and turbulence [45].
- Population density should be reconsidered. A larger body of students and a denser classroom or dorm room have a more potential in becoming the hotbed for transmitting the virus. Classes can be taught virtually, and those classes that require lab work or physical experiments can be spread out across different hours during the day to reduce student interactions [43].

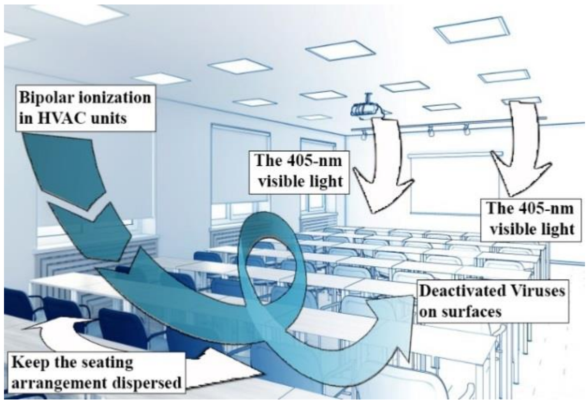

Figure 4. An illustration of the way different strategies can be incorporated into an existing classroom. Source of the base photo of a standard classroom: [46].

Other methods that can be considered high effort but are still within the realms of accessible technology are:

- Replacing the fixed-speed fan motors with the variable-speed ones to make sure that the control of airflow can be done smoothly and in order to provide a minimum setting that produces a lower speed airflow.
- Installing high-tech airflow-control systems, many of them are sensitive to pressure, to allow for an optimized adjustment of airflows.

6. High-tech solutions in controlling transmission of Covid-19

In the fairly recent scientific studies into how high-technology solutions might perform in battling the spread of Covid-19, several methods have been introduced and examined.

6.1. Filtration

Simply put using the air-purification methods that are based on filtration to reduce the risk of polluted air spreading. Many HVAC units in classrooms or high-density studying situations, especially in urban areas, already come with a filtration system for intake-air. Mechanical filters are rated based on the percentage of particles they remove, with the highest rated typically used in surgical or clean-room applications. High-Efficiency Particulate Air (HEPA) filters are most effective at removing the small particles [47]. To even be called a HEPA filter, the filters must remove 99.97% of particles about 0.3 microns. Most HVAC units in academic buildings, however, accommodate Minimum Efficiency Reporting Value (MERV) filters, which are tasked to filter out large particles (from 0.3 to 10.0 microns in size) [48]. Thus, in order to change the filtration methods of a HVAC system, some administrations might have to change their entire building’s ducts, exhaust vents and even door vents to accommodate the HEPA filters, and the HEPA filters themselves need to be checked and replaced regularly and with precision, meaning that the maintenance is sometimes doubled.

6.2. Ultraviolet germicidal irradiation (UVGI)

Another method would be to use electromagnetic light. UVGI removes 99.9% of harmful airborne viruses and bacteria moving through the HVAC system, spore growth (mold) growing on coils, drain pans, and UV compatible filters. The details of the system are very important (e.g., design of fixtures, lamp type, lamp placement airflow amount and mixing). Aerosolized viruses, according to the existing literature, are more vulnerable to UV damage than when they are suspended in a liquid or on a substrate [49].
Simply adding UV or UVC (Ultraviolet light type C) to an existing system without consideration of these factors has not been demonstrated to have a benefit [50]. However, as depicted in figure 5, the utilization of UVC in the airstream and/or in-room upper level has shown to be effective, and in-duct UVC systems inside air handling units can prevent a huge number of pathogens from entering or re-entering the indoor environment. It is important to note that this method is best used in combination with particulate matter filtration, carbon filtration (carbon capture from recirculation air), and dilution ventilation [51]. It is also crucial to consider that in the systems where the exhaust air-heat recovery is equipped with the fresh air system, the bypass can be installed either at the fresh air side or exhaust air side [52].

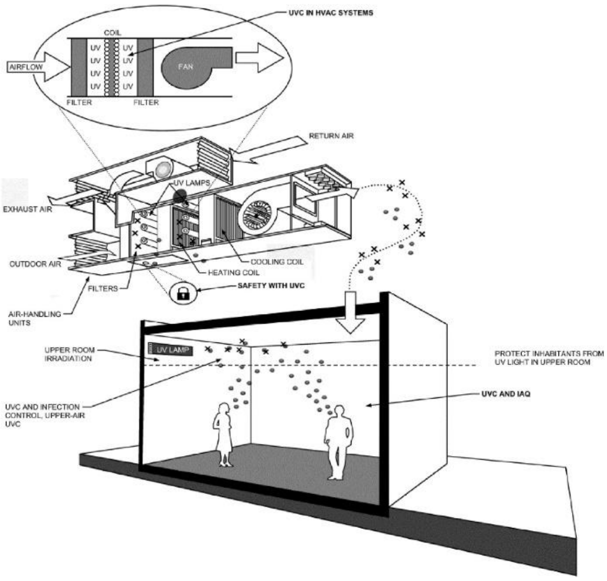

Figure 5. How UVC can be utilized to reduce pathogens in indoor air and on surfaces, while being installed in-duct and upper-room level. Source: [16].

6.3. Bipolar ionization

Bipolar ionization (also called needlepoint bipolar ionization) can also be regarded as an assistive technology that can be used in HVAC systems or portable air cleaners in order to help mitigate the risks of Covid-19 transmission. Ionization in HVAC systems generates positively and negatively charged particles, to be exact, high voltage electrodes create reactive ions in air that react with airborne contaminants including viruses [53]. This system can be modified to create mixtures of reactive oxygen species (ROS), ozone, hydroxyl radicals, and superoxide anions. Little research is available that evaluates its effectiveness in case of purifying indoor air from Covid-19 particles outside of lab conditions [54].
As it is typical of newer technologies, the evidence for safety and effectiveness is not as solid as more established methods, e.g., filtration. Bipolar ionization has the potential to generate ozone and other potentially harmful by-products indoors, unless specific precautions were specifically implemented in the product design and maintenance [55]. Many manufacturers try to reduce the generation of ozone by weakening the electric fields, which results in less ozone generation but also less efficiency; there are, however, ozone capturing solutions that are being examined alongside this technology [56].

6.4 405-nm visible light

Similarly, the 405-nm visible light has been touted as a method of purifying indoor air. The 405-nm visible light is sometimes referred to as "Near-UV" light; however, it is not in the UV spectrum, and as a visible light can be integrated into regular indoor lighting systems. It has been known to kill bacteria and fungi via different mechanism than the UVC method, by creating reactive oxygen species (ROS) to target naturally-occurring porphyrin molecules inside the microorganisms [57]. However, its effectiveness at killing viruses including SARS-CoV-2 has not been vigorously and methodologically researched or examined yet. However, it can be used as a method of continuous disinfection of air and exposed surfaces in occupied spaces [58].

6.5. Screening for infection

A high level of technology has been employed in detecting infection and optimizing the control of the virus spread. These technologies were implemented in methods from tracking the disease in real time to screening the individuals and mass testing via artificial intelligence controlling methods, digital thermometer and heat sensitive thermal cameras, and mobile phone applications for contact tracing in real time and web-based toolkits. The integration of digital technology into the administrative policies of a university can ensure that other methods of mitigating risk are optimized [59].

6.6. Internet of medical things (IoMT)

In many cases, the implementation of a comprehensive methodical integrated plan that responds to any threat in time is the best approach in curbing the spread of any disease. In the case of the threat of Covid-19, it might be an easier task to digitize and connect all elements of a university through IoMT than in other organizations due to the fact that the universities are already well-digitized entities and their staff and personnel are usually tech-savvy. Utilizing IoMT in pandemic mitigation can be done through several steps: application, architecture, technology, and security. In the more detailed levels, the artificial intelligence deals with data from heat cameras, contact tracing apps, and medical e-record block-chains to control and predict the spread of the virus [60].

All the methods recommended above have to be rigorously studied, and their real-life effects have to be examined in low-density and high-density situations. A high-density environment has always been associated with large numbers of cumulative infected cases of any outbreak; this element has revealed its fatal potential during Covid-19 [61]. Spaces like university dorms and university classrooms that are consistently occupied by a large number of people and are very rarely available for deep sterilizations (unlike commercial buildings during the weekends) have to have specific studies dedicated to observe the effectiveness of these methods in their environment during full-capacity and other times.

6.7. Integration of practical solutions into built space

Considering all that has changed in life due to the Covid-19 pandemic, it is crucial that architecture changes with the new demands. New designs and construction methods must not only prepare the indoor environments for any instances of Covid-19 endemic or variants but also be flexible enough to foresee other possible outbreaks. This idea itself presents a new issue; are the changes necessary to temporarily control the hazards of Covid-19 or are they the new normal [62]?

The instances of architecture being transformed after a pandemic are not few. For example, one of the ignitors behind the rise of modernism with its pristine aesthetic and abandoning of ornamentation was the need modernist architects felt to cross the threshold into an era clean of tuberculosis. Beside the aesthetics, the features that were supposed to bring in light, and rid the space of dust and pathogens, like large windows, vast spotless surfaces, and white paint were all a testament to the healing nature of the modern built space [63]. Many predict that similar changes are to be expected to happen post-pandemic; these changes most likely will gear towards reducing the costs, energy consumption, and difficulty of creating a healthier environment. This phenomenon is already being anticipated by the renewable energy market [64].

Humans instinctively try to avoid dangers and create barriers between themselves and harm. All built environments originally were created to act as such barriers in one way or another. Quarantine itself, a word familiar to us post-covid, was born out of the pandemics of the past. It acts as a spatial shield and temporary barrier between the infected and the healthy. It is one of the simplest forms of cushioning people through space and time [65]. Similarly, this pandemic has created its own demands on the construction world and barriers in the designing sector.

The integrated architectural solutions that are currently discussed as methods of designing for a post-covid era are:

- Creating a buffer space between the employees and customers, especially in retail spaces. For the purposes of this paper, this can also be applied to administrative offices of universities and library counters.
- Creating a disinfecting space in the foyer of buildings, by the help of UV-light or small doses of chemical disinfectants.
- Utilizing UVGI in the HVAC systems and in ducts while managing its ozone production to ensure a healthier indoor air.
- Many pathogens thrive in humid air in order to provide healthier air; controlling the levels of humidity is crucial. ASHRAE recommends maintaining relative humidity at 40%–60% as scientific analyses have concluded this humidity range is best for minimizing the spread of many airborne infectious organisms including influenza, and most likely SARS-CoV-2 [38].
- Utilizing proper filtration methods and increasing the air exchange rate of HVAC units, preferably portable high-efficiency particulate air (HEPA) fan/filtration systems.
- Administrating constant post-occupation CO_2 control as an indicator of proper indoor air quality.
- Limiting unnecessary occupation through digitizing work. This goes for limiting unnecessary interactions between the administrative staff of the university and its students, as well.
- Increasing the utilization of automatic faucets, door handles, and light switches.
- Maximizing outdoor spaces that can be used as waiting areas between classes such as terraces, roof gardens, and small plazas.
- Replacing fixed speed HVAC motors with variable speed motors.
- Cleaning and treating of recirculated air [66].
- Provide the air-supply of the HVAC system at ground level, and return air at the ceiling level as opposed to the current common design, which supplies and returns air at the ceiling level [38].
- Using fans to increase the effectiveness of open windows when the HVAC systems are not running.
- Ensure that restroom and kitchen exhaust fans are functional, well-equipped, and operating at full capacity when the building is occupied.
- In non-dormitory buildings, run the HVAC system at maximum outside airflow for 2 hours before and after the building is occupied [20].

7. Cost and energy

One of the issues that might curb the process of improving Covid-19 transmission mitigation practices is the financial cost of implementing each one of these methods. Another issue that can affect both the environment and the cost of the operation is the electricity and the energy consumption of each additional equipment. In order to fully grasp how green and costly these methods are, the following table is presented. To create a standardized comparable number, the cost of equipment was divided by the size of the area they hypothetically have to support and service. The same was calculated for the energy use based on the total area. The classroom in the hypothesis is considered to have an average area of 52 m_2 with 3 meters in height.

Table 1. A comparison between different methods based on cost and success rate.

Method	Cost of equipment per square meter	Complications	Overall additional cost	Overall effectiveness of method
Increasing air-exchange rate of an HVAC unit 15 ACH	An average of $28.19 for 1 air change, if the base was 10 ACH, increase: $140.9 [67]	More air means higher the capital/construction costs due to a need for larger fans, changing the size of the ducts, and adjusting heating/cooling capacity [67, 68]	For an average class $7,326.8 a year + $10,068 additional	Microbial levels 39.00 cfu/m_3 [69]
Increasing air-exchange rate of an HVAC unit 25 ACH	An average of $28.19 for 1 air change, if the base was 10 ACH, increase: $422.85 [67]	Steam heating, humidification system/cooling systems/fans, and pumping power would need to be adjusted to the new demands [67]	For an average class $21,988.2 per year + $30,204 additional	Microbial levels 22.00 cfu/m_3 [69]
Replacing MERV 8 filters with HEPA filters on HVAC units	Avg. cost of changing one MERV filter to HEPA is $67.5. For HVAC unit of a classroom, usually 4-8 filters are needed: $270 - $540 [70]	Upgrading ventilation system to compensate for resultant pressure drop is often necessary.	Installation and maintenance costs.	From an Avg. Arrestance of 80% and filtration of 3.0-10.0 microns to 99.97% for the size of 0.3 microns [71]
Using portable air cleaners with high	For a classroom of 52 m_2 the avg. unit costs $649.99	AHAM Clean Air Delivery Rate (CADR) can be used to	Filter replacement	Same as HEPA filtration in HVAC units.

efficiency filters	[72, 73]	properly size air-cleaners for any given space [74]	charges throughout use.	
Air Ionization installed in existing HVAC units (induct)	From $300 to $700 per a HVAC unit [75]	An Ozone control addition should be added to the device. EPA recommends using a device that meets UL-2998 standard certification [47].	-	Not enough scientific data on its purification success rate; however, it does deactivate the virus.
UVGI installed in HVAC systems or air-entries	$1,500 to $2,500 each unit [76, 77]	Average irradiance required for 90% inactivation in upper-room ultraviolet air disinfection if the ACH=8 is 84.829µW/cm_2 [49]	Particulates can shield virus from UV light; thus UV penetration should be enhanced meaning that cost might vary. [78]	Log reduction of log 0.602 to log 5.91. Survival rate of 1.65 to 0.0000012 for the virus. Keep in mind that photoreactivation viruses can repair UV damage [49].
Non-thermal plasma In a portable air sterilization device	$405.49 to $1,199 each individual unit [79] and [80]	Because of the production of ozone in the process of utilizing NTP, devices with Ozone control are recommended [81].	In the case of acquiring the portable device there is minimal additional cost.	3.1, 2, and 2.1log10 TCID50/ml reductions in hPIV-3, RSV and H5N2 virus respectively [82], meaning non-thermal plasma is an effective virucidal agent. Another report: almost 99% reduction [83]. Not enough data to be certain of NTP's effect on Covid-19 virus.
405-nm visible light	Total treatment cost of visible $light/Cu\ (II)/H_2O_2$ was determined to be 32.64 KWh/m_3 and 4.74$/$m_3$ [84] For a classroom of $52m_2 \times 4_m$ it is: $985.92.	Using 405 nm light on a continuous basis at lower levels can reduce level of microorganisms in the air of an occupied room or it can be set to higher levels for shorter periods of time in unoccupied space [85].	Added cost of maintenance and installation of the lights, which can vary.	After 8 hrs. of exposure achieving more 1.5 $\log_{10}$ reduction [85]
Digital thermometer and heat sensitive thermal cameras	Digital thermometer: $399 and thermographic camera (CCTV): $175 a piece [86]	Thermal scanners are effective in detecting cases who have developed a fever (i.e., have a higher-than-normal body temperature). However, they cannot detect people who are infected but are not yet sick with fever.	Cost of maintenance, installation, and constant monitoring	Temperature-based screening such as thermal imaging is not effective because, among other things, a person with Covid-19 may not have a fever [87].

For all the presented strategies to be standardized and comparable, we decided to divide the supposed cost of the implementation of a strategy (from initial cost of the device to other adjustments) by the ability of the device in terms of risk-mitigation in the classroom area it was supposed to cover; thus, the element of space is neutralized and each device has a cost per square meter numeration. By that value the effectiveness of one method is comparable to another method in both the cost and transmission mitigation capabilities. The goal was to be able to compare all the suggested methods; however, it is important to note that a series of strategies, as depicted in Table 1, carry additional costs, for example, improving the quality of filters reduces air-pressure simultaneously, and to compensate for that the air-ducts need to be adjusted and reconstructed, which inflicts additional construction cost. Furthermore, to have a unified value in how effective a method is in deactivating the virus, all log reduction results and microbe survival rate results were converted into percentage of success, as shown in figure 6. It is important to note that the majority of these results were from the analysis performed in the laboratory conditions, and many are based on similar respiratory viruses to Sars-Cov-2, not necessarily the Covid-19 virus itself.

Similarly, figure 7 depicts “the effectivity to average total cost ratio” of each method that has been previously introduced. As predicted, digital thermometers and heat sensitive thermal cameras due to their lack of ability in mitigating the cause of the transmission, the Covid-19 virus itself, have 0 effectivity in virus deactivation, and thus are the least effective method. It is important to mention that their impact on reducing the presence of symptomatic people sick with Covid-19 in an indoor environment, is calculable in the administrative control section of the hierarchy of control for Covid-19; yet in the engineering control section, as the pyramid itself depicts, other methods of air sanitizing and virus deactivation offer more protection.

In order to further illustrate the use and the practicality of these methods, the following flowchart was constructed. As figure 8 shows, when discussing these strategies, the initial step in finding a practical solution is to determine if that solution would need to be installed during the construction of a classroom or whether it can be added into the environment post-occupation. From there, both categories divide into three sub-sections on each side, titled managerial solutions, architectural solutions, and HVAC solutions. All the subsequent solutions are to be examined, even when two or more solutions are combined; each method should be examined on its own and within the system. A thorough analysis of these examinations helps the building managers and university administrations make decisions about the risks, required enhancements, and overall status of every classroom.

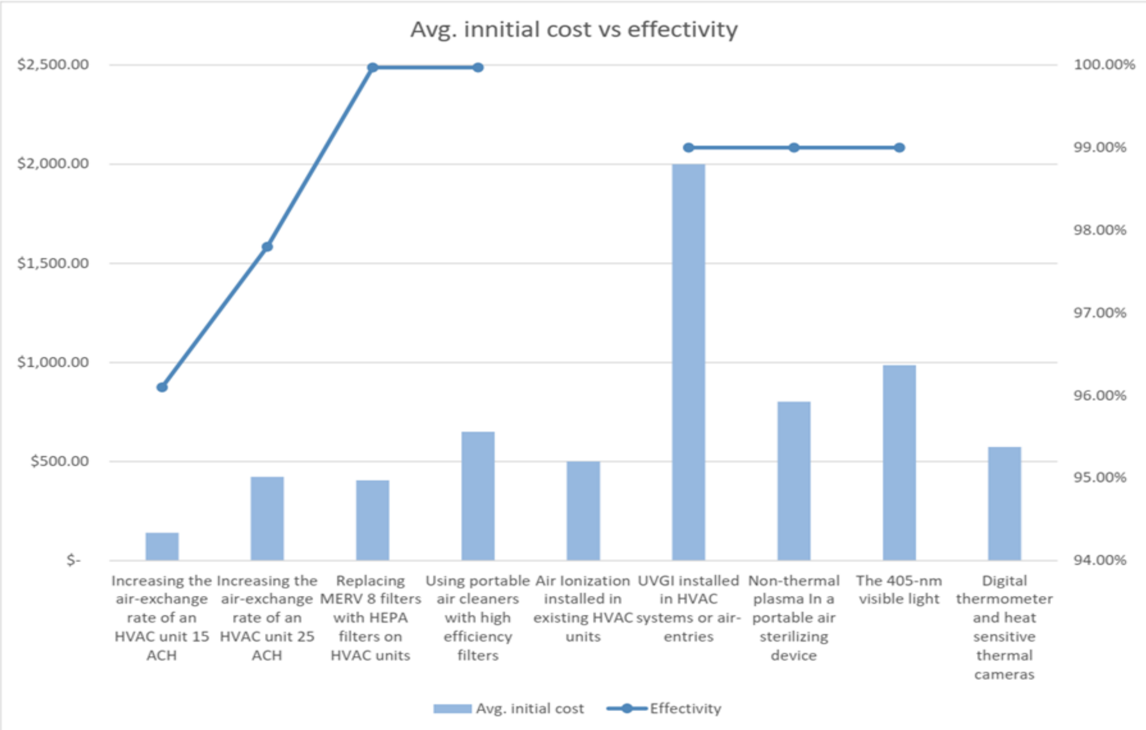

Figure 6. Comparison between initial cost of a device *vs.* its effectivity.

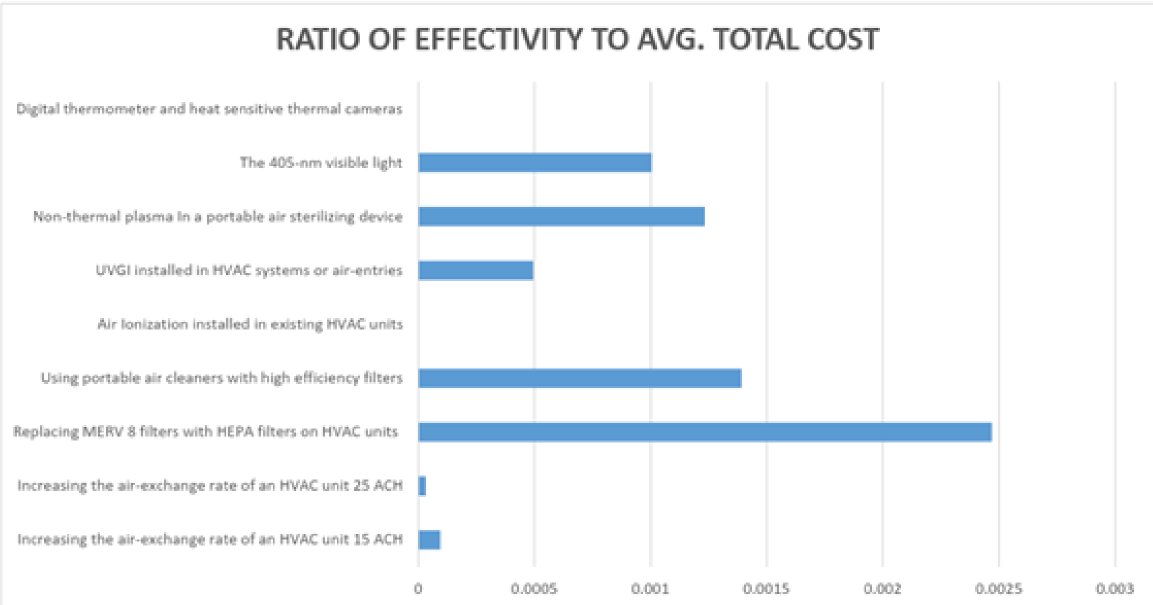

Figure 7. Ratio of effectivity of a method to average total cost of implementation.

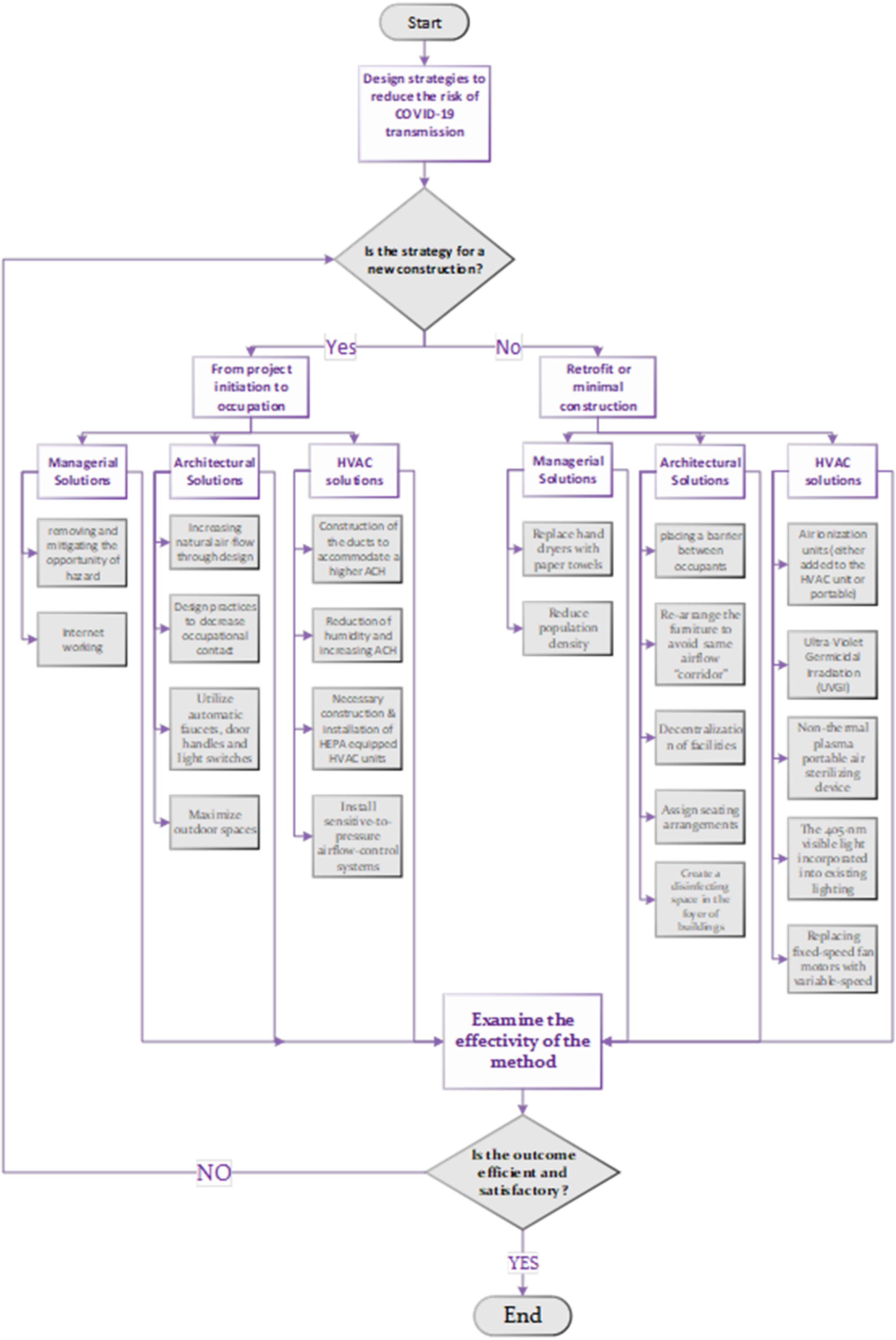

Figure 8. Result's flowchart.

8. Conclusion

In this review, we initially discussed the Covid-19 transmission risks in an indoor environment, and the properties this pathogen shares with other indoor-air polluters; the hierarchy of controlling this threat was consequently presented. Among the solutions the manufacturers and scientists offer to date, the HVAC solutions that promise the most effective outcomes were analyzed from a practical stand-point. The majority of the research on this particular route of engineering control concerning the threat of Covid-19 is lab-bound and still in its infancy; however, the commercial products utilizing these practices have been mass produced and utilized for other viral pathogens and microorganisms.

Besides upgrading air filtration, optimizing air-vent placements, increasing air exchange rates, and monitoring impactful environmental variables such as CO_2, PMs, humidity, and temperature, new technologies are effective in risk mitigation as well.

Among the reviewed methods, Replacing MERV 8 filters with HEPA filters on HVAC units is the most cost efficient and overall effective method in mitigating the transmission risk of the virus in a standard university classroom. UVGI installed in the HVAC systems or air-entries does impose the highest initial cost on an administration but it is also the most effective solution in deactivating the viral agents in an indoor environment, according to a research work.

In step with HVAC optimization, the architects must keep in mind that in the changing world we are living today it is far more important to create spaces that are flexible and adaptable over time as need for different types of protection arises. Buildings should protect people under all circumstances. In the case of this pandemic, protect their occupants from exposure to contaminants. Architects and urban planners must also design buildings and communities that can manage density better, keeping in mind that the needs of people may change and installations and operational systems might have to change with them as-well. However, it is always a safe bet to create environments that prioritize health-oriented construction practices, e.g., optimized circulation of airflow, spatial design, biophilic elements, and natural light. By setting these priorities and selecting the right building materials and HVAC systems, constructions can be built for healing.

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