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Energy-Efficient Strategies for Mitigating Airborne Pathogens in Buildings—Building Stage-Based Sustainable Strategies

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Abstract: The coronavirus disease (COVID-19) pandemic has had widespread global effects. The advent of novel variants of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus, along with the spread of diverse airborne viruses across different geographical locations, has caused reflective apprehension on a global scale. This resurgence emphasises the critical importance of carefully constructed structures installed with efficient ventilation systems, including both natural and mechanical ventilation techniques, as well as mixed-mode ventilation approaches in buildings. Building engineering and architectural designs must go beyond traditional considerations of economics and structural durability in order to protect public health and well-being. To attain a high quality of life, it is necessary to prioritise sustainability, energy efficiency, and the provision of safe, high-quality indoor environments. Empirical scientific investigations underscore the pivotal role played by conducive indoor environments in averting the transmission of viral diseases such as COVID-19 and mitigating challenges associated with sick building syndrome, primarily stemming from suboptimal indoor air quality. This work provides a summary and a SWOT (strength, weakness, opportunities, and threat) analysis of strategies designed for engineers, architects, and other experts in the field to implement. These strategies are intended for integration into new constructions and the retrofitting of extant structures. Their overarching objective is the minimisation of viral transmission within indoor spaces, accomplished in an energy-efficient manner consonant with sustainable development objectives. The significance of these strategies lies in their ability to impact changes to national and international building codes and regulations, strengthening infrastructures against probable airborne viral threats. Encompassing both object-centric and subject-centric approaches, these strategies collectively furnish a holistic framework for mitigating the dissemination of pathogens, exemplified by the SARS-CoV-2 virus and similar airborne viruses, across diverse typologies of buildings.

Keywords: buildings; COVID-19; indoor environmental quality; public health and safety; policy and strategy

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1. Introduction

Every tenth person on the earth has already been infected with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The condition is severe as one in every thousand people is already dead due to pneumonia and respiratory ailments occurring due to different variants of SARS-CoV-2 since it broke out in December 2019 [1]. The data are still not comprehensive as the figures are based on the reported data only, manipulated by several nations to maintain their global reputation and maintain law and order in the country. Actual data will be much worse than the presented data and can shake humankind if presented properly. Additionally, there are still no proven research and data on the global deaths due to organ failures and heart attack cases exacerbated by coronavirus disease (COVID-19), albeit neurological research proves that COVID-19 nudges the death toll in several other ways as well. Associated with COVID-19 cases are job loss, family loss, stigma and discrimination, domestic violence and abuse, exacerbation of pre-existing psychological conditions, loneliness and social isolation, grief and bereavement leading to depression, etc., as COVID-19 has also taken a great toll on public mental health [2,3]. These can all be said to be collateral deaths due to COVID-19, which may not have been considered in the reported data. Signs like frequent headaches, neck pain, shoulder pain, chest pain, back pain, pounding heartbeat, upset stomach, heavy chest, tight muscle, lumpy throat, blood clots and vascular issues, numb body parts, dry cough, acute breathlessness during a little physical work, etc., are prevalent among all age groups after COVID-19 [4]. “Long COVID”, “black fungus”, “depression”, “stress”, and many more medical conditions are still affecting the lives of individuals [5]. Omni-directional losses due to SARS-CoV-2 have affected humankind at each level, be it economic, social or cultural, and individual health. The impact of COVID-19 on non-human organisms remains insufficiently examined [6,7], and the interdependence between the health of domesticated animals and humans within built environments lacks comprehensive investigation.

Initially the virus was thought by some to be transmitted primarily through fomites and droplets with a transmission range of fewer than three meters [8], but it has always been known by most experts that all viruses are airborne in the form of minute particle aerosols. However, researchers find that aerosols are hugely responsible for speeding up infection cases along with the above two transmission modes, especially in closed structures, where re-suspension is higher and ventilation is inadequate [9–11]. Researchers throughout the globe eventually cut to the chase and cited airborne transmission of SARS-CoV-2 as a reasonable third path of spreading [12]. Recent studies designated aerosol transmission as the most dangerous mode of viral spreading as it leads to “Super-Spreading Events” (SSE) in buildings [13,14]. SARS-CoV-2 can travel more than three meters’ distance in aerosol form due to negligible gravitational force and a longer suspension period in the air [15].

The spread of SARS-CoV-2 within a building is directly influenced by the complexity of the human immunology, architectural design, occupancy schedule, and built environment conditions. Several organisations in various countries have suggested ways to abate the viral transmission of coronavirus in buildings. Apex research organisations dedicated to architecture, construction, building operation, and maintenance have issued several recommendations for COVID-19-safe built environments [16–23].

According to the World Health Organization (WHO), the risk of contracting COVID-19 is greater in crowded places and places that lack proper ventilation, where infected individuals spend extended periods in close proximity. COVID-19 outbreaks have been observed in locations where people gather closely indoors and engage in activities like loud talking, shouting, heavy breathing, or singing. Such places include restaurants, choir rehearsals, fitness classes, nightclubs, offices, and places of worship. To enhance indoor safety, WHO emphasises the importance of avoiding situations involving the “3Cs”: closed spaces, crowded conditions, and close contact. WHO recommends that outdoor gatherings are safer than indoor ones, especially when indoor spaces are small and lack sufficient outdoor air circulation. When it is not possible to avoid crowded or indoor settings, certain precautions should be taken. These include opening windows to increase natural ventilation indoors and wearing masks. WHO also offers comprehensive guidelines for small public gatherings and provides recommendations for improving ventilation and air conditioning systems, both for the public and for those responsible for managing public spaces and buildings.

In India, the Ministry of Health and Family Welfare has issued guidelines to prevent the spread of COVID-19 and has given special attention to ensuring the safe operation of office buildings. Suppose one or two COVID-19 cases are reported in a workplace. In that case, the recommended disinfection process will focus only on the places or areas that the affected individual(s) visited within the past 48 h. There is no need to shut down the entire office building or halt work in other areas. Once the disinfection is carried out following established protocols, work can resume as usual. However, if a more significant outbreak occurs involving multiple cases, the entire building must be temporarily closed for 48 h after a thorough disinfection process. During this time, all staff will be required to work from home. Work can resume in the building once it has been adequately disinfected and is declared safe for re-occupation [24].

The Council of Scientific and Industrial Research—Central Building Research Institute, Roorkee (CSIR-CBRI, Roorkee), in collaboration with concerned sister laboratories, has already issued two sets of guidelines at the national level for the prevention of SARS-CoV-2 in buildings in the past two years. The first guideline [16] was issued in May 2021 by the CSIR, which was further updated in the subsequent year based on the updated available knowledge and research. In 2022, the second version of the updated guidelines [17] was published in January 2022. All of the stakeholders associated with the building industry can follow these recommendations to safeguard themselves and others from COVID-19.

Several reputed organisations like Public Health Ontario (PHO), Canada; American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the US; Society of Heating, Air-Conditioning and Sanitary Engineers (SHASE), Japan; Representatives of European Heating and Ventilation Associations (REHVA); and European Centre for Disease Prevention and Control (ECDC), EU etc., released early guidelines to prevent the airborne transmission of COVID-19 in different types of buildings using single or multiple strategies. Apart from these organisations, governments around the world also enforced several rules to mitigate the pandemic situation and safeguard the general public from SARS-CoV-2 transmission in buildings. However, none of the guidelines provide suggestions for updating existing building stock and future buildings to prepare themselves (to prevent future outbreaks) according to the building phases.

WHO continually passed several instructions to the global population as per the updated scientific research and real-time information gathered from around the world. However, SARS-CoV-2-like pathogens are still a big challenge as they are still a step ahead of humans because of their highly mutable nature and longer durability in different conditions and environments. The most popular research organisations recommended maintaining relative humidity and temperature within controlled limits [16–23]. Among these recommendations, the common range of relative humidity and temperature is 40% to 60% and 24 °C to 26 °C, respectively, for a comfortable indoor environment, as shown in Figure 1. However, for a country like India, where there are different types of climates, and that too, with an ongoing climate change scenario, it is very difficult to maintain these stringent criteria (temperature and humidity) in the built environment. However, some upgrades to existing building standards and their enforcement at ground level (real time in buildings) will enhance public health, safety, and comfort. Highlighting these strategic upgrades from detailed scientific literature published and from grey literature is the novelty of this paper.

There are different types of buildings being used by humans individually on a daily basis. Considering the same situation, this article presents solutions to prevent viral transmission in the built environment, which can be applied in different building typologies without any alterations. A broader perspective with a wider application will help readers understand and select the best way to guide them about safety in buildings and maintain their health. To facilitate this, a comprehensive review of six strategies commonly adopted in the buildings was undertaken. Strategies, namely, ventilation, design, dimensions and directions, product-enabled prophylaxis, smart operations, signage and markings, policy, inspection, and certification were studied.

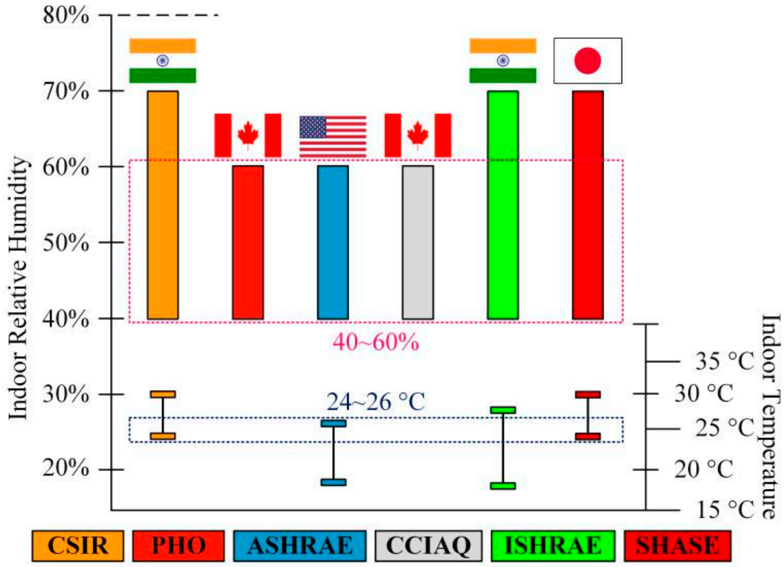

Figure 1. Recommended indoor air temperature and relative humidity for a comfortable indoor environment in buildings [25].

Furthermore, a SWOT (strengths, weaknesses, opportunities, and threats) analysis of all of the strategies was performed to ascertain the best and the most energy-efficient one as per building phase. Energy efficiency is closely linked to sustainability. Sustainability refers to meeting the needs of the present without compromising the ability of future generations to meet their own needs. Energy efficiency plays a critical role in achieving sustainability goals. Energy efficiency helps in conserving valuable natural resources by reducing the overall consumption of energy. When less energy is required to perform a task or meet a demand, fewer resources, such as fossil fuels or other non-renewable energy sources, are depleted. Improved energy efficiency leads to a reduction in greenhouse gas emissions and other pollutants associated with energy production. This is crucial for mitigating climate change and minimizing the environmental impact of energy use. Energy efficiency complements the use of renewable energy sources. By using energy more efficiently, the demand for energy from non-renewable sources decreases, making it easier to integrate and rely on renewable energy technologies which are more sustainable in the long run. Energy efficiency can result in cost savings for individuals, businesses, and governments. This economic aspect is important for long-term sustainability, as it ensures that economic activities are more resilient and can thrive without excessive energy costs.

Energy efficiency reduces waste by optimizing the use of energy in various processes. When energy is used more efficiently, there is less wasted energy in the form of heat or other by-products, contributing to a more sustainable and resource-efficient system. Sustainable practices, including energy efficiency, are essential for the long-term viability of societies and economies. By using energy more wisely, we ensure that energy resources are available for future generations, promoting sustainable development. Energy efficiency enhances energy security by reducing dependence on external energy sources and minimizing vulnerabilities associated with energy supply disruptions. A more energy-efficient system is inherently more resilient and sustainable. Many countries and regions have set energy efficiency targets and regulations to promote sustainability. Adhering to these regulations helps in achieving broader sustainability goals by reducing the environmental impact of energy consumption. Energy efficiency is a key component of sustainable development, addressing environmental, economic, and social aspects. By improving energy usage, one can contribute to a more sustainable and resilient future.

A comprehensive assessment of developed strategies for outbreak prevention that are practical and successful has been conducted in this work. Already, the COVID-19 pandemic has prompted significant policy interventions and revisions in building codes and standards to address the challenges posed by the virus and enhance public health and safety within indoor spaces. The strategies presented in this article can be embedded in national and international building codes in the upcoming revisions. These interventions have encompassed various aspects of building design, ventilation, sanitation, and occupant well-being. Notable guidelines and policy interventions throughout the globe that emerged in response to COVID-19 have been critically reviewed before suggesting upgrades in national building codes and built environment codes regulated by different organisations and governments.

This article is structured into five sections. The Section 1 presents the necessity of the work and establishes a background for the article. The Section 2 directly mentions ways to prevent viral transmission in buildings suggested by several international and national organisations, researchers, academicians, and policy makers. The Section 3 contains a SWOT analysis of various strategies to identify their strengths, weaknesses, opportunities, and threats. The Section 4 discusses the current requirement and the best solution and practices according to the SWOT analysis results as well as the status of the building (planning, designing, construction, operation, and maintenance stage). Eventually, the Section 5 concludes this study. It highlights the obviousness for further research to develop universal guidelines and update national standards (national building code) and other similar standards/codes to prevent viral transmission in different types of buildings in the future.

2. Airborne Transmission Prophylaxis Strategies

The majority of COVID-19 infections are discovered to occur indoors. However, the planning, design, and construction of buildings are not considered part of the viral transmission prevention strategy. However, the operation stage of current buildings is considered mostly by several guidelines to prevent viral transmission. Some guidelines issued were also focused on the maintenance stage of buildings. Overall, there is no reliable defensive strategy against the transmission of infectious illnesses inside structures.

Furthermore, there are currently no generic national guidelines for the planning, designing, construction, operation, and maintenance phases of existing buildings intended to avoid viral transmissions. The same is absent from most of the global literature, but that needs to change to mitigate against viral infection spread in future. Hence, there is a need to develop national viral transmission prevention standards for different types of buildings or upgrade the existing building standards. The risk of disease transmission inside a building can be significantly decreased by taking infection prevention design into account during the architectural planning and design stage, using virus prevention products in buildings during the execution of the construction process, operations, and maintenance, using advanced building management systems, and also developing a healthy indoor environment during maintenance, repair and upgrading work, etc. As presented in Figure 2, several strategies are presented in this section after a critical review of the available scientific literature and information. For the prevention of viral transmission in buildings, multiple strategy selection will be more effective than applying an individual strategy in any stage of the building.

2.1. Ventilation

Ventilation is the process of exchanging air using mechanical or natural means by bringing in outside air that is fresh and eliminating interior air that may carry viruses and other contaminants. It will be easier to mitigate the threat of COVID-19 by improving interior ventilation and air quality, especially for long-range (>3.0 m) dissemination [8]. Any interior area must have appropriate ventilation, whether that is achieved naturally (by opening windows and doors outside) or artificially (via mechanical ventilation systems or central air conditioning units). An indicator of ventilation is the number of times per hour that the air in a room or area is exchanged for fresh air or air changes per hour (ACH). The

European standard EN-16798 [26] has recommended 36 m^3/person/h (10 L/person/s) in COVID-19-like situations.

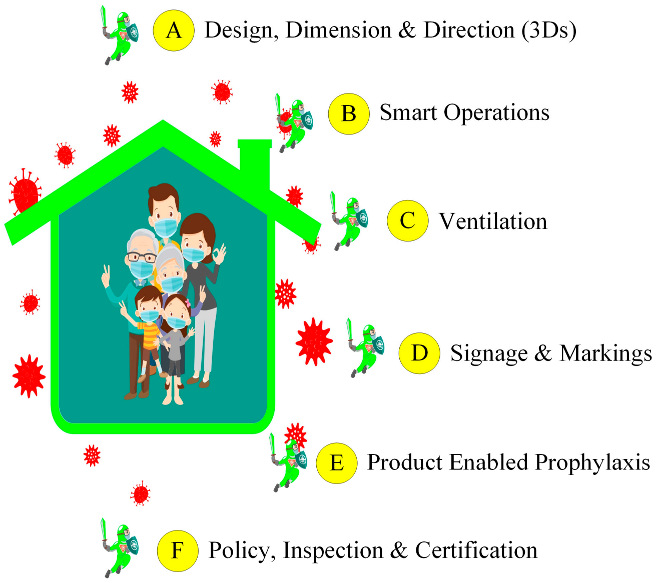

Figure 2. Recommended strategies for airborne pathogen prophylaxis in buildings.

Several guidelines have been issued by other organisations, such as the WHO, the Centers for Disease Control and Prevention (CDC), and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), to provide recommendations for improving ventilation and reducing the risk of COVID-19 transmission.

Along with other precautions, increasing the number of air changes can lower the chance of COVID-19 transmission [27]. Monitoring carbon dioxide (CO_2) has been used to encourage individual behaviour in enhancing ventilation and is likely to be helpful in increasing a person's safety against viral transmission [28]. Strategies like 100% fresh air with no re-circulated air, the use of appropriate filters, an extension of ventilation system operation hours, and regular maintenance of heating, ventilation, and air conditioning (HVAC) systems can help in transmission prevention in buildings [29]. HVAC systems, if well maintained and tailored for usage in the COVID-19 pandemic, may play a complementary role in reducing possible airborne transmission of SARS-CoV-2. When possible, adjust all building HVAC systems as per updated recommendations, and for this, the CSIR guidelines on the ventilation of buildings for SARS-CoV-2 virus may be followed [17].

2.2. Design, Dimension, and Direction (3Ds)

The role of building design, dimensions (height, width, length, working area, covered area, and fixed and movable furniture), and orientation of fenestrations (window, door, exhaust, etc.) is vital in mitigating poor indoor environmental conditions in buildings and creating "passive immune buildings" (PIB). Several public health bodies around the globe recommend maintaining a safe distance (approximately 1.8 m) within a building to prevent SSE. To achieve the same, the buildings must be designed properly, and each occupant must have an appropriate indoor working area for their work. Designers must consider wind direction as one of the most important parameters in the design for different seasons and, according to the building typology, to maintain sufficient ventilation indoors. Any airborne particles that may be present in the air can be diluted by bringing fresh air of good quality (AQI < 100) from outside into the building through a proper combination of building design and opening direction and operations. Buildings must be designed in segments so that if any particular area contains pathogens, the rest of the building can be kept safe for operations. Multizone transmissions can be restricted in buildings by designing the building properly in advance or by retrofitting the existing building in a way that can keep occupants safe from indoor transmissions.

Spaces must be designed to allow for physical distancing. Arrange furniture and workstations to maintain at least 6 feet (2 m) of distance between individuals. Limit the number of people in confined spaces to reduce crowding and increase airflow. Ensure that airflow follows a unidirectional pattern, with clean outdoor air entering at one end of the space and exiting at the other. Design spaces to direct airflow from clean areas toward potentially contaminated areas. Consider zoning or partitioning larger spaces to create smaller areas with independent ventilation systems. Design spaces with windows and doors in such a way that they can be opened to facilitate natural ventilation with outdoor air and ensure cross-ventilation by opening windows on opposite sides of a room to create a flow of fresh air. When designing buildings considering HVAC systems, consider the placement of supply and exhaust vents to promote directional airflow tuned with natural airflow. Select an optimised system that allows for adjustable ventilation rates supported by natural ventilation positively, which can be increased when needed. Ensure that rooms have adequate volume and ceiling height to allow for proper air circulation and dilution of contaminants. Design in such a manner that the zone of higher probability remains less populated, and the movement in that zone will be negligible. Design stairwells and elevators to facilitate one-way traffic and improve airflow. Pay special attention to designing areas like bathrooms and kitchens, which may produce more aerosols. Use exhaust fans and enhanced ventilation in these spaces, along with proper design. Regularly inspect and adjust the 3Ds in the early stage of the building phases to reduce the overall cost and save energy.

2.3. Product-Enabled Prophylaxis (PEP)

"Product-enabled prophylaxis" as a specific term or strategy for COVID-19 prevention in buildings is not a widely recognised or standardised concept in national or international guidelines. However, it is important to note that the landscape of COVID-19 prevention strategies and guidelines needs to evolve. New approaches and technologies that emerged during and after the COVID-19 pandemic must be included in national and international guidelines as a separate section, and it is also a positive move to update the national building codes accordingly.

Several types of products that can kill or neutralise the SARS-CoV-2 virus are available in the market. CSIR has also developed several products for the prophylaxis of COVID-19 in the past three years, which are briefly mentioned in the guidelines [17]. These products can help greatly in reducing COVID-19 transmission in buildings such as air purifiers, cleaners, and disinfection devices. Several organisations recommend installing portable air cleaners and disinfectants in small and medium-sized rooms at strategic locations. Advanced safety products can also help in reducing the probability of getting sick. Ultraviolet germicidal irradiation (UVGI)-based products can be used to disinfect surfaces inside buildings to prevent transmission [17].

2.4. Smart Operations (SO)

The concept of "Smart Operations" as a strategy for COVID-19 prevention in buildings was not widely recognised or standardised in national or international guidelines. Most guidelines at present and during the pandemic primarily focused on well-established measures such as wearing masks, physical distancing, improving indoor air quality through ventilation as well as filtration, and promoting hygiene. However, the use of technology and smart building solutions for enhancing building operations, including monitoring air quality, occupancy management, and contactless access control, has been discussed in research as a means to help prevent the spread of COVID-19. These technologies can be part of a broader strategy to create safer indoor environments. The field of smart buildings and their role in public health measures will likely continue to evolve, and future building guidelines and recommendations may address this strategy in greater detail.

Due to several technological advancements in smart buildings, operations can also be smartly designed. Sensors and internet of things (IoT) can be used in buildings to enable them to perform smart operations. The building manager may ensure occupants use face coverings in buildings to upkeep a hygienic environment with the help of cameras and artificial intelligence (AI), which can detect defaulters automatically. Maintaining a robotic supply for safe building operation is another long-term approach. As per the occupancy, face coverings and masks, cleaning solutions/sprays, disinfecting wipes, hand sanitiser, gloves, etc., can also be provided in a building using robotics. Smartphone apps, machine learning, and AI can transform the built environment into quite a safe indoor environment against the SARS-CoV-2 virus.

2.5. Policy, Inspection, and Certification (PIC)

Timely development and implementation of policies hugely contribute to creating a safe and healthy indoor environment. Working from home is a practical strategy to prevent the everyday congestion of buildings, roads, and public transport. Work-from-home rules have enabled many businesses to go on operating throughout this epidemic while also protecting the health and safety of their employees. Flexible work-from-home rules can minimise the number of individuals entering a building on any given day, which reduces the number of people who could become sick if someone in the building is contagious, even if it is not during such a volatile period. It is more likely that someone will not enter the building when infected if employers provide workers enough sick days. This significantly reduces a building's ability to spread infections. However, this is largely affected by labour laws within specific jurisdictions. When eating, drinking, and sharing food, adhere to the best procedures in the building recommended by the COVID-19 prevention recommendations. Individuals who arrange an event or social gathering in built spaces must adhere to the current event regulations [30]. Shared areas are the most prevalent locations for SSE in various types of buildings. Therefore, it is advised to reduce the shared spaces in a building. If it is inevitable to cut down the crowd at certain places, proper signage and markings are needed to guide the crowd for safe practices.

Similarly, looking into the new concept of co-living housing in metropolitan cities as a viable alternative to traditional paying guest accommodation for working professionals (bachelor or singles), there is a need to develop a policy for such types to minimise the spread of the virus. The strong synergy from these concepts maintains building occupant health all year long, not only during a pandemic throughout the world. Before considering the "policy, inspection, and certification" strategy in general, it is essential to keep in mind that this strategy can vary by region, evolve, and be influenced by culture, socioeconomics, local conditions, and existing regulations. The use of policy, inspection, and certification (PIC) measures to ensure building safety and compliance with health guidelines is a broader concept that can be part of a comprehensive strategy for COVID-19 prevention.

2.6. Signage and Markings (S&M)

The use of signage and markings in buildings as a COVID-19 prevention strategy has been widely recommended and suggested by both national and international guidelines. These visual cues and informational materials can help guide building occupants and visitors on best practices for preventing the spread of COVID-19, such as maintaining physical distance, wearing masks, practising hand hygiene, following one-way traffic patterns, etc. Major health organisations like the WHO, the CDC, and various international health authorities have guided on the importance of using signage and markings in indoor spaces. Many countries and regions have also issued guidelines that incorporate signage and markings as part of their COVID-19 prevention strategies for buildings. In India, for NBC, a separate chapter is needed for signage and markings not only for public health and safety but also for all of the aspects related to buildings.

Installing educational signs in toilets can assist in reminding individuals to wash their hands after using the restroom and improve the chances that people are washing their hands. Permanent signs in toilets promoting good handwashing procedures will help remind the users of their safety. Install signage that explains best practices for preventing viral transmissions in buildings. These posters can also be used in digital form, which can present updated information easily. Information on building-specific viral transmission prevention strategies can be displayed on digital screens installed at the entrance of the building. Place all posters where they will be seen by as many people as possible, such as in building lobbies, public spaces, break rooms, near elevators, and at the entrances to unit/department work areas and buildings. Buildings must have updated signs that reflect the most recent information and markings to direct people toward COVID-19-appropriate behaviour, such as maintaining a safe distance, a no-talking zone, wearing masks, regular sanitising, etc.

All of these strategies have strengths, weaknesses, opportunities, and threats. Some strategies complement each other, while some work effectively individually. For an effective prophylaxis of airborne COVID-19-like pathogens, a complex ratio of these strategies is required depending upon several conditions in real-time scenarios.

3. SWOT Analysis

SWOT is associated with the evaluation of strengths, weaknesses, opportunities, and threats of the processes, enabling better strategic planning [31]. It is an important diagnostic tool that is often used at the beginning of any process to develop and plan strategically for the future [32]. SWOT analysis has been adopted in various research focused on analysing construction practices, adopted technologies, innovations, etc., from a scientific perspective [33]. SWOT is made up of two factors broadly classified into internal and external ones. The internal factors, i.e., strength and weakness, are often associated with the distinguishing parameters and characteristics that separate a parameter from its competition or put it at a disadvantage [34]. On the other hand, opportunity is classified as one of the external factors [32] and is associated with the competitive edge that the approach may have over others. Finally, the last external factor, i.e., threat, symbolises the parameters that inhibit the performance of a particular approach [34]. Although SWOT has been established as an important tool for the formulation of strategies owing to its benefits, its adoption in the civil engineering domain has been scarce [31]. The studies employing SWOT have mainly been associated with the use of building information modelling (BIM) in the Polish construction industry [32], achieving sustainable construction through the management of construction and demolition waste [34], engineering, procurement, and construction (EPC) project procurement [33], and cementitious material and environmental issues [31,35]. However, its adoption for the analysis of strategies for the maintenance of sustainable indoor air quality (IAQ) parameters remains absent.

SWOT analysis is used to evaluate the key strategies for the expected performance in the buildings to prevent airborne infections. It is used to identify the most effective prophylactic strategies according to the building stage (plan, design, construction, operation, and maintenance).

3.1. Ventilation

In Figure 3, a comprehensive SWOT analysis of the ventilation strategy is presented. The analysis examines the strategy's internal strengths and weaknesses, as well as external opportunities and threats. This visual representation in Figure 3 provides a succinct overview of the strategic factors influencing the ventilation strategy, aiding stakeholders in understanding the key elements shaping its success and potential challenges.

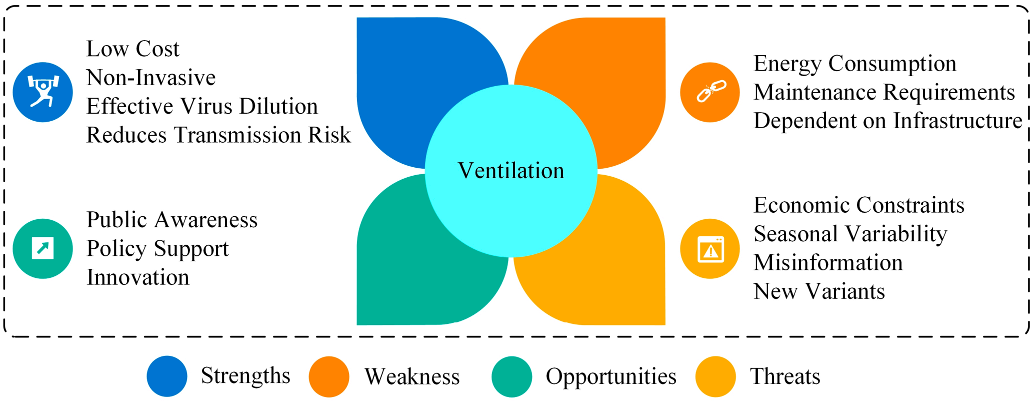

Figure 3. SWOT analysis of ventilation strategy.

3.1.1. Strengths

Effective virus dilution is the first strength of the ventilation strategy to improve IAQ and prevent airborne transmission. Proper ventilation can help dilute and disperse indoor air contaminants, including viral particles, reducing the risk of infection. The second strength is the low-cost implementation of this strategy, but it is highly dependent on the building stage. Earlier building stage considerations, i.e., in planning and designing, of ventilation will result in low overall cost. However, later building stages, like operation and maintenance, will cost more to address the ventilation strategy. The implementation of measures such as opening windows and exhaust fans is often relatively inexpensive compared to other preventive measures like widespread use of air purifiers, air disinfectants, mechanical ventilation systems, etc. Another strength of this strategy is that it is a non-invasive strategy. Ventilation does not require direct intervention in individuals' bodies, making it non-invasive and generally well received by the public. According to the wider literature with in-depth research, it is evident that good ventilation reduces airborne transmission risk, which is the ultimate strength of this strategy. Adequate ventilation can significantly decrease the risk of COVID-19 transmission in enclosed spaces, such as schools, offices, and enclosed public structures, both static (buildings) and dynamic (transportation).

3.1.2. Weaknesses

Ventilation as a strategy to prevent airborne transmission contains weaknesses like infrastructure dependency, energy requirements, and timely maintenance, among several others. Effective ventilation relies on the availability and functionality of proper HVAC systems or the ability to open windows, which may not be feasible in all built settings. Similarly, energy requirement is another weakness of this strategy. Improving ventilation may increase energy consumption in some cases, which could be costly and have environmental implications. One more prevalent weakness that emerged after the expert discussion is maintenance requirements. HVAC systems and all other mechanical systems require regular maintenance, and ensuring that they meet ventilation standards can be challenging, especially in older buildings. Similarly, naturally ventilated buildings, windows, doors, exhaust openings, etc., require proper maintenance for smooth operation as well as for preventing the infiltration of mosquitos and other unwanted life-form invasions in built spaces while enhancing ventilation and airflow in buildings.

3.1.3. Opportunities

Ventilation as a strategy creates a pool of opportunities. Among several, some are increased public awareness, market growth opportunities, innovation in existing technologies, and enhanced policy support, which can both support and upgrade the existing practices in different types of buildings. The COVID-19 pandemic has increased awareness of the importance of IAQ, creating opportunities for businesses and industries that offer ventilation solutions. This results in the refinement of the skilled workforce and enhances employment opportunities. The demand for effective ventilation systems has spurred innovation in air filtration and purification technologies, leading to the development of more efficient and cost-effective solutions. Additionally, several types of other technological and design interventions were innovated throughout the globe as a positive outcome of the pandemic. Governments and regulatory bodies may introduce policies and guidelines to promote improved ventilation in public spaces, providing opportunities for businesses and industries involved in ventilation systems.

3.1.4. Threats

Looking at the adverse side of the ventilation strategy, some threats can externally affect the proper implementation of this strategy in buildings. Threats like economic constraints, misunderstanding due to misinformation, seasonal variability, and the emergence of new variants are of great concern. Some individuals, businesses, and institutions may face financial challenges when trying to upgrade their ventilation systems, especially in sectors severely affected by the pandemic. Misinformation or misunderstanding of ventilation strategies could lead to improper implementation, potentially reducing their effectiveness or causing unnecessary expenses. Seasonal changes in temperature and weather conditions can impact the feasibility of natural ventilation methods, making them less effective in certain regions during certain times of the year. The emergence of new COVID-19 variants and other airborne pathogens could potentially affect the effectiveness of ventilation strategies, as some variants and pathogens may be more transmissible or resistant to ventilation measures.

3.2. Design, Dimension, and Direction (3Ds)

The graphical representation serves as a valuable tool for stakeholders, facilitating a nuanced comprehension of the pivotal elements that determine the success and potential challenges for 3Ds. Figure 4 illustrates a thorough SWOT analysis of the 3Ds strategy. This analysis meticulously scrutinises both the internal facets—strengths and weaknesses—and the external dynamics—opportunities and threats—of the strategy. The visual depiction in Figure 4 succinctly encapsulates a comprehensive perspective of the strategic determinants influencing the 3Ds strategy.

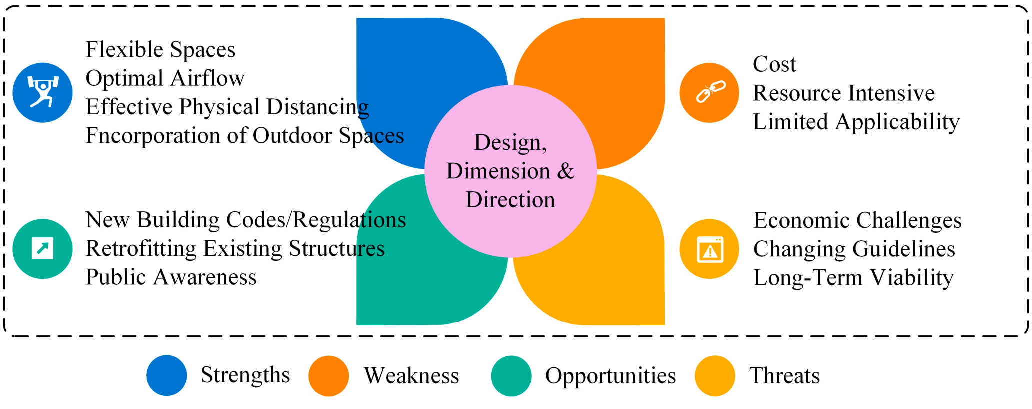

Figure 4. SWOT analysis of 3Ds strategy.

3.2.1. Strengths

The "design, dimension, and direction (3Ds)" strategy is the second most effective strategy when considering long-term sustainability with energy efficiency and affordability. Effective physical distancing is required to prevent viral transmission. Proper building design can allow for more spacious layouts, facilitating physical distancing measures among occupants, which is a crucial strategy for preventing COVID-19-like transmissions. Designing buildings to maximise natural ventilation and airflow can help dilute and disperse airborne contaminants, reducing the risk of virus transmission. Buildings designed with flexible and adaptable spaces can facilitate the implementation of various safety measures, such as rearranging furniture or creating isolation areas. Incorporating outdoor spaces is another strength of this strategy. Designing buildings with easy access to outdoor areas like patios or courtyards can provide additional safe spaces for occupants.

3.2.2. Weaknesses

There are some weaknesses of the 3D strategy as well; these are cost constraints, applicability limitations, and resource intensiveness. Implementing specific building design and dimension changes may be costly, especially in existing structures where modifications are needed. Some existing buildings may not be easily adaptable to these strategies due to structural constraints or limitations in available space. Designing and constructing new buildings or renovating existing ones to incorporate these strategies can be resource-intensive and time-consuming.

3.2.3. Opportunities

The opportunities available for the 3Ds strategy are that there is a need for new or updated building codes and regulations, structure retrofitting, and enhanced public interaction for awareness. Governments and regulatory bodies may introduce building codes and regulations that promote COVID-19 prevention measures, creating opportunities for architects and builders to innovate and adapt their designs. There is an opportunity for retrofitting existing buildings to incorporate COVID-19 prevention features, which can revitalise older structures and improve their safety. Increased public awareness of IAQ and safety may drive demand for buildings designed with health and safety in mind. This will enable certified engineers and architects to showcase their advanced knowledge and innovations targeting sustainable development goals.

3.2.4. Threats

Considering the threats of the 3Ds, a strategy will enable the tackling of issues while implementing it in real time. The first threat is economic challenges. Economic downturns and budget constraints may limit the resources available for building design changes and renovations. The second threat is from rapidly changing guidelines. Evolving COVID-19 guidelines and recommendations may require frequent adjustments to building designs, potentially leading to confusion or disruptions. Lastly, long-term viability is also a threat to this strategy. Some design changes made in response to the pandemic may not be suitable for long-term use or may become obsolete once the pandemic subsides.

3.3. *Product-Enabled Prophylaxis (PEP)*

Figure 5 presents a comprehensive SWOT analysis of the PEP strategy. The visual representation in Figure 5 concisely captures a holistic view of the strategic factors shaping the PEP strategy.

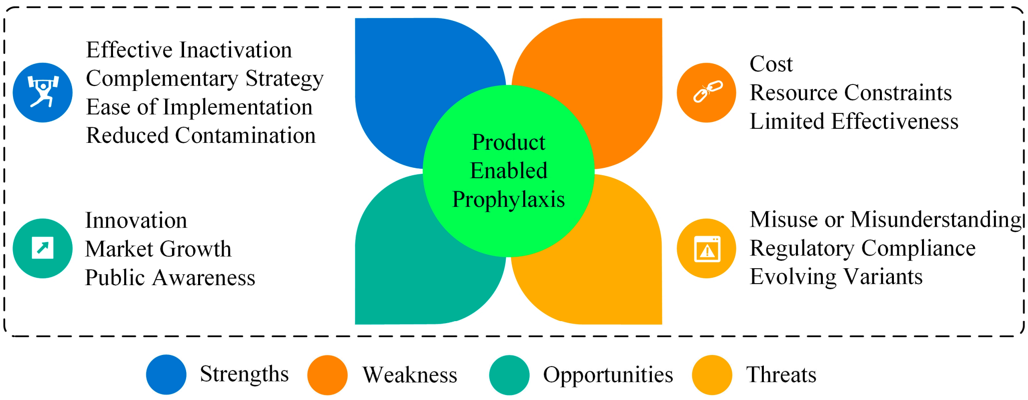

Figure 5. SWOT analysis of PEP strategy.

3.3.1. Strengths

Germicidal UV or also known as Ultraviolet-C (UV-C)-based products and some other innovative technologies can achieve effective inactivation. Some products, such as UV-C disinfection systems and air purifiers with HEPA filters, are effective at inactivating viruses like COVID-19 and enhancing IAQ. Product-enabled prophylaxis can complement other preventive measures, such as vaccination and mask wearing, to create a layered approach to COVID-19 prevention. New products available in the market are user-friendly, and with time, they can be more advanced with applications of IoT and AI, making the implementation easy. Many of these products are relatively easy to install and maintain, making them accessible to a wide range of organisations and building types. The use of antimicrobial surfaces and coatings can help reduce the risk of surface contamination and transmission.

3.3.2. Weaknesses

Implementing this strategy can be costly for some users. The cost of purchasing and maintaining these products can be a significant barrier for some individuals as well as organisations, especially those with limited resources. Implementing product-enabled prophylaxis may require additional resources, including staff training and ongoing maintenance, which may not be feasible for all buildings. The effectiveness of some products may vary depending on factors such as product quality, proper installation, and adherence to maintenance protocols. Apart from effectiveness, there is always a concern related to the efficiency, efficacy, and reliability of the product for a particular indoor space, which is additionally affected by user behaviour and usage type.

3.3.3. Opportunities

There is an opportunity for continuous innovation in product-enabled prevention, leading to the development of more effective and cost-efficient solutions. The demand for COVID-19 prevention products has created opportunities for businesses and industries specialising in these technologies. COVID-19 is just a starting point for several nations to consider public health, safety, and comfort an important part of their buildings. Increased awareness of indoor air quality and surface hygiene may drive demand for these products in various settings.

3.3.4. Threats

Improper use or misunderstanding (handling/placement/operation) of COVID-19 prophylaxis products can lead to reduced effectiveness or potential health hazards. Regulatory compliance is also a threat. Changes in regulations and standards related to these products may pose challenges to compliance and implementation. New variants of COVID-19 may impact the effectiveness of existing prophylactic products, requiring ongoing adaptation and investment.

3.4. Smart Operations (SO)

In Figure 6, the smart operation (SO) strategy using a SWOT analysis is presented. The figure provides a quick summary of the key aspects that affect the SO strategy.

3.4.1. Strengths

Smart building systems can provide real-time data on IAQ, thermal comfort, visual-acoustical data of occupants, occupancy, and other relevant metrics, enabling proactive responses to COVID-19 risks. Automation and sensors can optimise ventilation, ensuring that indoor air is adequately exchanged, which is crucial for diluting viral particles. Smart technologies enable contactless entry systems, touchless elevators, and voice-activated controls, reducing high-touch surface interactions. Building operators can use data analytics to make informed decisions about space utilisation, cleaning schedules, and occupancy limits to mitigate COVID-19 risks. The point to be noted is that good operating and maintenance manuals are required from the design stage, and it must be kept in mind at that time.

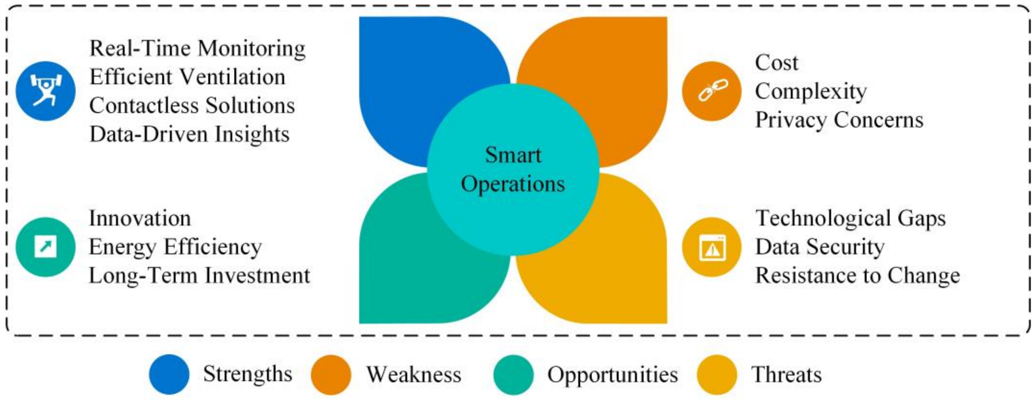

Figure 6. SWOT analysis of smart operations strategy.

3.4.2. Weaknesses

Implementing and maintaining smart building systems can be expensive, and not all organisations may have the financial resources to invest in such technologies. Smart building systems can be complex to set up and require specialised knowledge, which may pose challenges for some building operators. The collection and analysis of data from smart building systems can raise privacy concerns, especially if not handled properly.

3.4.3. Opportunities

The COVID-19 pandemic has spurred innovation in smart building technologies, creating opportunities for new solutions that enhance safety. Smart building operations can lead to energy savings, making it an attractive option for organisations looking to reduce costs and their carbon footprint. Investments in smart building technology can provide long-term benefits, enhancing building operations even beyond the pandemic.

3.4.4. Threats

Technological gaps are a serious threat to this strategy. Not all buildings may have the infrastructure or technical capabilities to implement smart building operations effectively. Data security is also a threat to this strategy. Handling sensitive data related to building occupants and operations may expose vulnerabilities to cyberattacks, putting privacy and security at risk. Proper training and the availability of clear and concise operating manuals to stakeholders is an additional concern under threats. One more threat is resistance to change. Building occupants or operators may resist or have difficulty adapting to new smart building systems, hindering their effective implementation.

3.5. Policy, Inspection, and Certification (PIC)

Figure 7 showcases a thorough SWOT analysis of the policy, inspection, and certification (PIC) strategy. The visual depiction in Figure 7 succinctly encapsulates a comprehensive perspective of the strategic elements influencing the PIC strategy.

3.5.1. Strengths

Establishing policies and regulations provides a clear framework for COVID-19 prevention, ensuring consistency and standardisation across different sectors and regions. Inspection and certification processes can effectively enforce compliance with safety measures, promoting adherence to guidelines and regulations. Organisations and businesses are held accountable for their COVID-19 prevention efforts, reducing the likelihood of negligence or non-compliance. Certification programmes can build public trust by demonstrating that organisations prioritise the safety and well-being of their customers and employees. However, the requirements need to be supported by a solid and clear legal framework in order to be enforced.

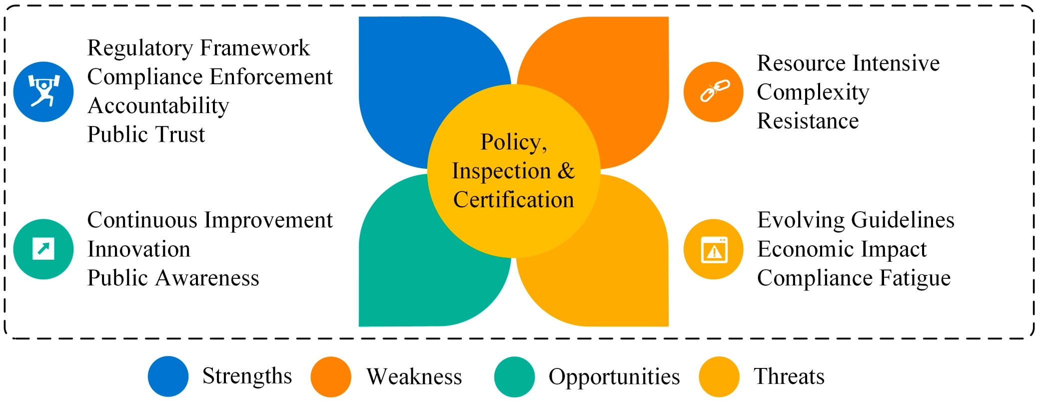

Figure 7. SWOT analysis of PIC strategy.

3.5.2. Weaknesses

Implementing and enforcing policies, conducting inspections, and managing certification programmes can be resource-intensive, requiring trained personnel and funding. Managing a complex system of policies and certifications can be challenging, leading to potential confusion and administrative burdens. Some businesses and individuals may resist or push back against stringent policies and inspections, leading to issues of policy compliance.

3.5.3. Opportunities

Ongoing inspections and certifications create opportunities for organisations to improve their COVID-19 prevention strategies continually. The development of new technologies and methods for inspection and certification can enhance efficiency and accuracy. These initiatives can raise public awareness about the importance of COVID-19 prevention measures and the commitment of organisations to safety.

3.5.4. Threats

Rapidly changing guidelines and recommendations can make it challenging to keep policies and certifications up-to-date and relevant. There needs to be a single point/entity that oversees the rules and guidelines specifically related to IEQ parameters. Strict policies and enforcement can pose economic challenges for businesses, leading to financial strain and potential closures. Over time, businesses and individuals may become exhausted with stringent policies and inspections, leading to reduced compliance.

3.6. Signage and Markings (S&M)

In Figure 8, an exhaustive SWOT analysis of the S&M strategy is shown. The visual representation in the figure shows a concise overview of both the internal and external strategic factors influencing this strategy.

3.6.1. Strengths

Signage and markings are a visual communication strategy to safeguard building users. Signage and markings provide clear and visual communication of COVID-19 preventive measures, making it easier for individuals to understand and follow guidelines. Standardised signage and markings ensure consistency in conveying important information across various locations, reducing confusion. Implementing signage and floor markings is a relatively cost-efficient method of promoting COVID-19 safety measures. Signage and markings can be easily adjusted or updated to reflect changing guidelines and requirements.

Figure 8. SWOT analysis of S&M strategy.

3.6.2. Weaknesses

While signage and markings can communicate guidelines, they may not guarantee compliance, and some individuals may choose to ignore them. Signage provides limited information and may not address all aspects of COVID-19 prevention, such as the need for proper mask wearing and hand hygiene. The production and disposal of signage materials can have environmental consequences, including waste generation and visual pollution. An important issue associated with the adequacy and applicability of S&M is its close interdependence on public knowledge and the public's will to adopt/accept the guidelines unmonitored/unsupervised. This may be the biggest challenge.

3.6.3. Opportunities

Opportunities exist for innovation in signage and markings, such as using smart signage that can provide real-time information or integrating QR codes for contactless information access. Effective signage can contribute to long-term behavioural changes related to hygiene and safety, even beyond the pandemic. Signage can raise public awareness about the importance of adhering to COVID-19 safety measures that contribute to community health.

3.6.4. Threats

Poorly designed or ambiguous signage can lead to miscommunication and misunderstanding, potentially undermining preventive efforts. Another threat is vandalism or removal by people. Some individuals may vandalise or remove signage, reducing its effectiveness and increasing maintenance costs. Excessive signage and markings in a space can lead to information overload, making it less likely that individuals will pay attention to important messages.

4. Discussion and Recommendations

The outbreak of the worldwide pandemic in the form of COVID-19 has made it imperative for planners to look into an efficient ventilation system. Moreover, not just the new buildings but suitable measures should be put into place that can cater for the ventilation system in the existing buildings.

4.1. New Buildings

Planning for a new building whilst keeping in mind the IAQ parameters is an important step in dealing with the challenges of the spread of pathogens. During the planning of new buildings, the majority of the measures, i.e., ventilation, 3Ds, and smart operation, can be implemented. The adoption of an adequate natural ventilation system is the easiest of all, requiring no additional expense, and can be planned for during the planning and design stage itself. Furthermore, sensor-based facilities can be more focused on that can aim to reduce human contact with the designated surface. It will therefore reduce the chance of the spread of the pathogen, thereby reducing its transmission. An example of this has been narrated in the works of [36], where the authors posited the use of the Toe-to-Go elevator system which can help in reducing surface contact and thus prevent pathogen spread. Apart from having a contactless system, it is essential that all of the points and building areas are identified at the design stage that can have the possibility of becoming a pathogen-spreading centre. These areas should be clearly marked with signs and markings guiding people and visitors to undertake precautionary measures in the event of any incident. Although having these systems and checks in place can ensure the restriction of the spread of the pathogen, it is strictly pertinent that regular monitoring of the systems should be undertaken for their robust operation and implementation. To ensure this, regular inspection, monitoring, and legislations should be put in place that should be followed by all of the associated stakeholders. The development of new buildings should be achieved according to the specified building codes that are developed to overcome such situations. The building plans should be carefully vetted for them to be as per the set governmental regulations and norms.

4.2. Existing Buildings

The application of various strategies in new buildings can be ensured easily; however, it is the existing buildings that are more important to be focused on. With a long service life, these are designed to serve for a considerably long time, and hence it becomes essential that such buildings should be modified concerning the maintenance of an efficient IAQ system.

Of all of the strategies, ensuring optimum ventilation is the most essential and one of the easiest strategies to be adopted. Natural ventilation in the form of opening windows, etc., needs to be practiced. However, some of the existing buildings may not have an efficient natural ventilation system, and therefore, to overcome such problems, efficient HVAC systems throughout the building should be installed. Furthermore, the installation of an ultraviolet germicidal irradiation (UVGI) system can also enable and help us to tackle the problem of airborne pathogen transmission [37]. Secondly, although it is nearly impossible to change the design, dimensions, and directions of existing facilities, certain retrofitting approaches can be undertaken that can ensure the reduction in virus transmission. An example of this has been narrated in the works of [38], where the authors recommend vertical installation of plants in the building wall. These plants are thought to absorb certain harmful chemicals [39] and also prove to be a cheap, energy-efficient system. Secondly, Ref. [38] recommends the retrofitting of existing handles, bars, rails, etc., with copper alloy material, as the use of copper has been found to be efficient in restricting the transmission of coronavirus [40]. Moreover, such buildings should adopt a phase-wise installation of mobile and sensor-based systems for the operation of doors, windows, blinds, etc. Apart from ensuring a swift transition towards the adoption of technological system, the buildings should have clear markings, signs, and instructions for dealing with unwarranted situations during its utilisation. The installation of relevant instructions and markings should be practiced at the critical locations and various entry and exit points to keep the users informed of the norms and guidelines that should be followed.

Finally, the adoption and implementation of these measures and strategies can only prove to be helpful with the regular inspection and monitoring framework. This can be incorporated by conducting mock drills and scenarios to test the efficacy of the installed systems. During monitoring, the functioning of the systems should be evaluated, and timely and planned rectification measures should be incorporated to maintain the planned system efficacy.

As nations strive to attain net-zero emissions and pursue de-carbonisation, it is imperative that they do not overlook IAQ, as neglecting this aspect can result in the development of unhealthy or 'sick' buildings. On the positive side, building health solutions are gaining popularity as a result of the COVID-19 breakout. Some of these may become statutory requirements in some locations to avoid another pandemic of this scale. In addition, new and novel crowd management solutions for buildings will most certainly be a popular issue in the upcoming months and years. Many novel techniques and strategies will protect the public in buildings from highly transmissible viruses like SARS-CoV-2. Revolving doors will probably start to appear more frequently or even be mandated by law for new building projects as they do not require anybody to touch them. However, revolving doors are not suitable considering persons with disabilities, so there is need to find alternative solutions like automatic doors that can ensure everyone can access and navigate spaces comfortably and safely.

Furthermore, it is conceivable that this epidemic may lead to advancements in the design of touch-free cabinets, drawers, and other buildings, as well as furniture components. At present, building architecture reveals several flaws in planning, design, construction, and operation as a result of the problem of this unforeseen disease breakout named COVID-19 (which may again strike at any time in the future). Therefore, the strategies mentioned above can be applied at different phases of the building process. Existing buildings can eliminate the present faults in their maintenance (retrofitting) stage. Building phases, namely, planning, designing, construction, operation, and maintenance, are tabled down with these strategies in Table 1. At each level, several strategies can be implemented as per the requirements.

Table 1. Building phases and energy-efficient COVID-19 prophylactic strategies (✓ represents the applicable strategy in particular building phase).

Building Phases	Strategy-1	Strategy-2	Strategy-3	Strategy-4	Strategy-5	Strategy-6
	Ventilation	3Ds	PEP	SO	PIC	S&M
Planning	✓	✓	-	✓	✓	-
Designing	✓	✓	-	✓	✓	-
Construction	-	✓	-	✓	✓	✓
Operation	✓	-	✓	✓	✓	✓
Maintenance	✓	✓	-	✓	✓	✓

To increase the ability of buildings to deal with COVID-19-like outbreaks in the future, viral transmission prevention guidelines should be adopted to strengthen virus transmission prevention in buildings. Following the adoption of various strategies throughout the building planning, designing, and construction stages, the strategies should also be executed during the building operation and maintenance phases (retrofitting). In this direction, the ventilation rate based on wind action can be worked out using Equation (1), as defined in the national building code [41].

$$Q_W = k \times A \times V \quad (1)$$

'Q_W' denotes the rate of flow (m^3/h). 'k' denotes the coefficient of effectiveness and has fixed values of 0.025, 0.6, and 0.3 for rooms having windows on one external wall only, for wind perpendicular to opening, and for wind at an angle less than 45° to opening, respectively. 'A' denotes the smallest opening area (sqm), and 'V' denotes wind speed (m/h).

The implementation of effective health intervention measures, home isolation, and disinfection procedures was found to be highly significant, especially when viral transmission was active and happened fast. It is recommended that a platform be developed that can universally manage, monitor, identify, and treat viral transmissions throughout buildings before, during, and after the peak transmission time. Multidisciplinary research, such as research on indoor environmental quality, epidemiology, medicine, public health and safety, engineering and architecture, big data, internet of things, rapid prediction models based on advanced computation techniques, etc., still need to be thoroughly investigated if comprehensive viral transmission prevention and control in buildings are to be achieved. In various types of buildings, the combination of the stated solutions will produce a safe and healthy indoor built environment. As presented in Figure 9, some of the sustainable development goals can be achieved by applying these strategies in different phases of the building process.

Figure 9. Achievable sustainable development goals.

5. Conclusions

COVID-19 resurgence is reiterating the value of building indoor environmental quality and building ventilation, cleanliness, hygiene, and proper maintenance. Buildings can either help prevent infectious diseases or facilitate their transmission. To avoid airborne exposure in buildings, occupants, owners, and building managers should implement infection prevention and control measures based on a complete building hazard assessment. This includes employing suitable combinations of administrative and engineering controls, sufficient ventilation, proper designing (dimension and direction), product-enabled prophylaxis, smart operations, the implementation of policy, inspection and certifications, proper signage and correct markings, proper training, safe working procedures, enforcement of personnel protective equipment, etc.

In alignment with the five distinct building stages, the strategic choice of an optimal virus prophylactic approach, harmonised with energy-efficient practices, will propel the building industry towards sustainability, concurrently advancing public health and safety. Modern buildings are still ineffective in efficiently preventing the transmission of infectious diseases, and there is currently no standard guideline for the same in the national building code (NBC) of India and in several other national and international building codes. This study emphasises the need to develop viral transmission prevention standards, particularly for buildings and the built environment, as well as a combination of extensive multidisciplinary research that necessitates serious efforts, substantial time, and resources. This work has a long way to go because it requires extensive and diversified study.

Furthermore, scientists and decision makers should gather long-term viral transmission data and study pathogenic risks like SARS-CoV-2. They should work on establishing appropriate standards for viral transmission prevention in buildings and create unified platforms for collecting data to develop effective evaluation techniques. Eventually, readers can select different sets of strategies or individual strategies presented in this paper to mitigate viral transmission in buildings where they live, work, and spend their time.

The challenges of changing construction standards may differ by jurisdiction, but a deeper understanding of pandemic and post-pandemic considerations will contribute to positive improvements over time. Future papers containing other researchers' perspectives on the feasibility of the supplied strategy recommendations in different places will add valuable refinement to this study finding. According to building phases, selecting the optimum virus prophylactic strategy in accordance with energy efficiency will move the building industry towards sustainability along with public health and safety.

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Abbreviations

Abbreviation	Expanded Full Form
ACH	Air Changes Per Hour
AI	Artificial Intelligence
AQI	Air Quality Index
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIM	Building Information Modelling
CBRI	Central Building Research Institute
CDC	Centers for Disease Control and Prevention
CSIR	Council of Scientific and Industrial Research
COVID-19	Coronavirus Disease
ECDC	European Centre for Disease Prevention and Control
EPC	Engineering, Procurement and Construction
HEPA	High Efficiency Particulate Air
HVAC	Heating, Ventilation, and Air Conditioning
IEQ	Indoor Environmental Quality
IoT	Internet of Things
NBC	National Building Code
PEP	Product-Enabled Prophylaxis
PHO	Public Health Ontario
PIB	Passive Immune Buildings
PIC	Policy, Inspection, and Certification
QR code	Quick Response Code
REHVA	Representatives of European Heating and Ventilation Associations
S&M	Signage and Markings
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
SDGs	Sustainable Development Goals
SHASE	Society of Heating, Air-Conditioning and Sanitary Engineers
SO	Smart Operations
SSE	Super-Spreading Events
SWOT	Strength, Weakness, Opportunities, and Threat
UV	Ultravoilet
UVGI	Ultraviolet Germicidal Irradiation
WHO	World Health Organization

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