

Article

Assessment of the Change in Design Strategy of Apartment Buildings in the Post-COVID-19 Pandemic Era

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Abstract: The world entered the post-COVID-19 era of coexistence with viruses, but people are still concerned as to whether there will be another virus outbreak in the future. Research on virus defense in the construction field is still underway, and considerable suggestions were proposed. If it seems these suggestions were adopted in many buildings, why is the pandemic still out of control? The main focus of this study is to explore a sustainable design strategy that should be adopted by apartment-style buildings in the post-pandemic era in terms of media, sensory, and action elements, and to analyze the applicability of these measures in specific buildings. The study analyzes cases of high-rise apartment-style buildings and used methods such as simulation analysis, direct observation, and comparative analysis to compare the design measures before and after the pandemic. The study shows that, while these measures mainly affect the environmental and social aspects of sustainability, some aspects of old buildings remain difficult to address. The existing standards of new building design need to be adjusted to make the necessary changes. Through our analysis, we concluded that, although the original green building system provides a good foundation for the adjustment of housing in the post-pandemic era, residential design should provide a more reliable framework for possible future pandemic defense. The study is based on the collation of research conducted by architects and experts, and presented in the relevant literature, and the specific analysis of completed apartment buildings within the context of the pandemic situation. This study provides a direction for apartment buildings to meet the challenges of sustainable development and paves the way for a clearer future in the field of construction building.

Keywords: post-COVID-19 pandemic era; apartment building; residential design; sustainable design; built environment; human health and well-being; green building technology



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1. Introduction

Over the centuries, viruses played a significant role in shaping the human living environment. The successful control of the bubonic plague in the 14th century enabled cities to open up large public environments; the outbreaks of tuberculosis and the Spanish flu promoted housing reforms; the onset of cholera and typhoid fever prompted the reform of water supply and drainage systems [1]; and the plague in the 19th century changed the structure of residential sanitation systems design. Even the modernist esthetic is owed, partly, to outbreaks of tuberculosis [2]. Ventilation systems improved after the SARS-CoV-1 outbreak. The COVID-19 pandemic that occurred in 2019 is expected to propel residential building changes to adapt to various health concerns. In recent years, we became concerned with the increase in the frequency of acute infectious disease outbreaks, such as SARS-associated coronavirus (SARS-CoV), influenza A virus subtype H1N1 (H1N1 flu), Middle East respiratory syndrome coronavirus (MERS-CoV), Zaire ebolavirus (Ebola virus), and

COVID-19 (COVID-19 virus). It is evident that COVID-19 will not be the last pandemic, and infectious diseases will continue to threaten the world.

Each pandemic inflicted significant losses on the lives, livelihoods, economies, and property of people worldwide. Through the analysis of multiple major pandemics, it is evident that residential buildings became the primary spatial environment for isolating the source of infection and breaking the chain of transmission due to the clear physical boundaries they provide. However, due to the high population density in apartment-style buildings, these buildings and their surrounding environments also became susceptible to cross-infection. This duality presents a challenge to the design and construction of traditional residential buildings. In some countries, this necessitates a systematic reform of the apartment building design systems to ensure the healthy performance of housing, as human health is a significant aspect of sustainable development [3].

COVID-19 is the worst health disaster of the century to date [4]. It will remain for a long time, and society is bound to enter a post-pandemic era in which pandemic levels will fluctuate and linger for long periods of time [5]. People started to adapt to living with the virus [6]. No research institution can predict how long this situation will continue, but it is certain that it became the backdrop of people's lives. Viruses are constantly changing the world, from lifestyle to architectural functions to urban planning. Housing is one of the building types most impacted by the pandemic, with apartment buildings being the predominant form of urban housing. Against the backdrop of living alongside the virus, the design strategies of housing need to be adapted to ensure sustainable development. Achieving the sustainable development goals is, at present, more important than ever [7].

Since the emergence of COVID-19 as a global problem, numerous studies investigated the impact of the building environment on its spread. In 2022, Mehdi Alidadi and Ayyoob Sharifi reviewed 4264 papers and identified seven main elements from the perspective of the built environment: density, land use, traffic and mobility, housing conditions, demographic factors, socio-economic factors, and health-related factors. These literature reviews primarily focus on urban planning factors, urbanization, density, traffic and travel behavior characteristics, environmental factors, smart city deployment, and the social determinants of health, and discuss the drivers of COVID-19 transmission, its effects on nature, settlements, and residents, as well as how urban planning can help to mitigate the effects of pandemics [8].

The quality of housing is a critical factor that directly impacts people's living environment, particularly in the context of the ongoing COVID-19 pandemic. It is essential that housing is designed to effectively provide social isolation and protection from the virus and other potential infections. The method of home isolation will truly become the container of life [9]. Due to the expectation that an increasing number of people will continue working from home even after quarantine periods, the future of home design is likely to undergo significant changes [10]. High-density populations may be the cause of poor sanitary conditions and the spread of infectious diseases [11]. For apartment houses, contact with other residents of the shared area is inevitable, so future designs should focus on the foyer from apartments [10]. Post-pandemic housing may introduce more zoning and there may be open spaces to ensure flexible and adaptable areas that make housing more sustainable and adaptable to changes in needs and lifestyles [11]. The literature review on resilience shows that many researchers and institutions place emphasis on the indicators of resilience. Over time, researchers became concerned with the general characteristics of resilience, such as self-sufficiency, self-organization, decentralization, diversity, versatility, flexibility, adaptability, modularity, connectivity, and inclusiveness [12–14]. These concepts also apply to the resilience of cities to withstand pandemics.

While the literature reviewed above indicates that there are good housing design directions, in terms of the functional streamlining of residential areas, there is a contradiction between the isolated residence and fire evacuation policies, which makes fire evacuation a hidden danger. To ensure resilient and sustainable communities, it is crucial to adjust the design of new apartment buildings according to fire evacuation policies and retrofit the

existing buildings to adapt to the new reality. By creating self-sufficient environments that can resist disease outbreaks, residents can remain comfortable at an efficient home, which reduces the psychological impact of such outbreaks.

Numerous studies revealed the connection between environmental factors and the transmission of COVID-19. For instance, temperature, humidity, light, air particles, and microbes in the air are associated with the spread of the virus. Ijaz et al. found that the virus thrives in a moderately humid environment [15], while Holtmann et al. observed that low temperatures promoted COVID-19 transmission in the early stages of the outbreak in Barcelona [16]. Additionally, Ward et al. observed that the drop in the relative humidity in Sydney led to an increase in the number of COVID19 infection cases [17]. For indoor spaces, strategies that help to improve health include increasing natural light, improving ventilation, and reducing toxic substances, for which it is necessary to add plants and other natural materials. For this, the design stage is very important. Options to avoid sick building syndrome and improve air quality include skylights, large windows, roof terraces, balconies, and courtyards [18].

In terms of construction equipment, Pengcheng Zhao analyzed cases of secondary infection in high-rise buildings in 2022. The study examined the impact of drainage system, light shaft, and ventilation shaft design on the vertical transmission of COVID-19. The research shows that the vertical transmission pattern of COVID-19 is particularly noticeable, especially in old residential areas, where drainage systems may be leaky, and in indoor apartment buildings, where drainage pipes may be damaged [19].

In terms of construction technology, discussions about the impact of pre-fabricated buildings and smart city technology on future housing are ongoing. The application of smart city technology proved to be useful to address the COVID-19 pandemic. Several governments employed smart city technology to track people infected with the virus, and may switch from using mobile devices and remote sensors to digital data sources for this purpose [20].

Different researches focused on the factors influencing the spread of COVID-19 and made various recommendations to limit these factors. These studies analyzed many factors affecting the health performance of residential buildings from macro- and micro-perspectives, and also provided valuable suggestions for sustainable-development-based construction techniques and strategies. Many of these strategies are part of green building recommendations, and were already implemented in many buildings. Therefore, why are these buildings unable to stop the spread of the virus? We found that there is no study that systematically applied these sustainable strategies in a built environment to verify their feasibility and adaptability from the perspective of green buildings. Sustainability is, at present, widely recognized as an important concept in the construction industry. To ensure the sustainability of buildings, different countries and regions adopted green building technology routes that are suitable for their regional climate and national conditions. The traditional pillars of sustainability are the environment, society, and the economy [21]. The concept of sustainable development involves improving the quality of life, so that people can live in a healthy environment and improve their social, economic, and environmental conditions [22]. However, the COVID-19 pandemic had a direct impact, primarily, on the social pillar [23], followed by the environmental pillar, thus creating an imbalance in the sustainable development of residential buildings. It is important to note that these three pillars are designed to interact with each other, and true sustainability can only be achieved when all three pillars are balanced.

This study conducts a literature review of the latest data sources and identifies 47 anti-epidemic design strategies that have the potential to impact the three pillars of sustainable development. We then analyzed the applicability of these strategies in current design cases and assessed their impact on building sustainability. The overall aim is to provide insights that support the future sustainable development agenda.

Previous research suggests that adjusting housing construction techniques is necessary to create a sustainable and healthy environment during pandemics. However, there is

a lack of consensus on which specific adjustments are needed, leading to a lack of focus in the field. This study has a two-fold aim. (1) To systematically organize the design strategies used to combat the pandemic in the literature into three categories: medium strategy, sensory strategy, and treatment strategy. The medium strategy refers to factors such as air and water quality, which impact the environment. The sensory strategy refers to factors such as sound, light, heat, and humidity, which impact the user experience. The treatment strategy refers to factors such as fitness facilities, humanistic construction, and health services, which impact the overall health and well-being of users. (2) To use the guidelines recommended by the literature reviewed above to identify, through a case study, the most important direction for adjustment and to evaluate the applicability of the above design strategies in the pandemic context using simulation parameters.

2. Methodology and Theoretical Framework

First, we gathered design initiatives, compiled the design strategies that are frequently mentioned in the literature, and determined the origin and quantity of the initiatives to be applied. The second step was to organize the design strategies according to medium, sensory, and treatment strategies, and to classify them according to the social, economic, and environmental pillars of sustainability. The third step entailed data analysis, which incorporated the strategies into the project to analyze their feasibility and applicability. Then, we selected the strategies that were not applicable to the case project and analyzed the reasons behind their non-applicability. The final step was to discuss the design framework.

2.1. The Collection of Design Strategies

This study conducted a review of the relevant studies using Web of Science, Google Scholar, ScienceDirect, and other search engines, and identified a total of 36 literature sources related to apartment building design strategies. After the analysis of the research content, 20 sources were found to be relevant to post-pandemic apartment building design strategies. After organizing the design strategies that consistently appeared alongside scientific-based recommendations in the 20 literature sources, a total of 47 design strategies were obtained. Some of them were literature review papers, and others were empirical research articles.

Mehdi Alidadi et al., based on a review of 164 papers, identified that the transmission of the virus is influenced by seven main factors, namely density, land use, traffic and mobility, housing conditions, demographic factors, and socio-economic and health-related factors [8]. Melika et al. proposed a conceptual framework for the resilience of cities to pandemics by conducting a systematic review of the literature on COVID-19. They also proposed general principles for the resilience of houses, communities, and cities at the regional and national levels [24].

Table 1 presents strategies used in the study cases according to three aspects: media, sensory, and treatment strategies. It also highlights which pillars of sustainability are affected by these strategies. The paper lists a total of 47 strategies, including 9 medium, 9 sensory, and 29 treatment strategies. Some of these strategies are green building features, but different requirements are proposed in the context of the pandemic, and others are the features of building changes driven by the pandemic. The combination of the two strategies forms a more systematic main feature of post-COVID-19 architecture. Among these strategies, the commonly used green building features include 29 items, mainly focusing on treatment.

Table 1. Design strategy used in apartment building during the pandemic.

	Environment	Society	Economy
Medium strategies	Ventilation design ¹ Door and windows design ¹ Air quality control ¹ Pollution protection Measures for water supply systems Pollution protection measures for sewage system Measures to avoid pollution in drainage systems Reserve water sources Kitchen and bathroom diversion ¹		Building materials
Sensory strategies	Outdoor temperature control technology ¹ Outdoor humidity Control Technology ¹ Indoor thermal comfort ¹	Floor spacing ¹ Natural daylighting ¹ Sunshine time ¹ Natural daylight ¹ Adjustable shading louver ¹ Daylight and sleep aid design Acoustic environment design	
Treatment strategies	Vertical greening technology ¹ Landscape design ¹ Self-cleaning space Reserve energy Renewable energy ¹ Garbage management ¹	Contactless technology ¹ Public spaces with sufficient social distance Balcony design ¹ Outdoor space design ¹ Building spacing ¹ Fire evacuation and isolation design Reasonable foyer design Public space layout Refuge design Isolation space and toilets for infected members of the family Flexible interior space ¹ Smart community system ¹ Smart home ¹ Community fitness condition ¹ Buildings for humans ¹ Cleaning and management of shared facilities Window-to-wall ratio ¹	ICT infrastructure at the home level Building density ¹ Population density ¹ Urban agriculture ¹ Prefabricated architecture ¹ BIM technology ¹ Reasonable household design

¹ Green building feature.

2.2. The Choice of Sample Site

Although sustainable buildings are not specifically designed to prevent the spread of viruses, one of the underlying principles of such buildings is the adaptation to environmental changes in order to create a healthier and more sustainable building environment [25], which could potentially reduce the transmission of viruses in the future.

It was found that there are differences in space and time between building environment and human factors in terms of virus transmission [4]. The impact of the geographical location and climate on the transmission of viruses in green buildings can vary significantly, and the standards for implementing green buildings can also differ across different regions. Therefore, drawing a general conclusion about green buildings across different areas could prove difficult.

Furthermore, when selecting buildings for analysis, it is essential to consider certain factors, such as appropriate building size, occupancy rate, and the age of the green facilities.

In this study, only apartments certified as green buildings in the hot summer and warm winter areas of China with a hot and humid subtropical climate were selected for analysis so as to obtain common insights. This study selected the Jiankeyuan residential project located in Nanning, Guangxi, a hot summer and warm winter region in China. The project comprises four 33-storey high-rise residential buildings that were completed in 2011. The building scale is moderate. The project adopted the traditional green building technology route.

2.3. Research Methods

Sustainable buildings, based on a comprehensive design, allow us to understand how to achieve our research goal. We analyzed the characteristics of the various adopted strategies, including which strategies can be used as remedial measures, which strategies are not applicable to existing buildings, and which strategies need to be included to new buildings.

To accomplish this, the following methods were employed in this paper:

1. Case study analysis;
2. Direct observation and analysis;
3. Chart analysis;
4. Comparative analysis;
5. Simulation analysis based on the project design model.

In the data collection phase, based on a summary of the relevant literature, we utilized Table 1 to analyze the 47 design strategies required during the pandemic as our theoretical framework to guide our proposed design. We further evaluated whether the case project constructed according to the current norms fulfills the requirements for pandemic mitigation. Through this evaluation, we analyzed the relationship between these design strategies and sustainable development.

Finally, we assessed the feasibility and application of the 47 design strategies in projects. This analysis provided insights into the potential benefits and challenges of implementing these strategies in practical settings, helping to identify any necessary modifications or adaptations to the design strategies.

Using the method of direct observation and analysis, this paper examined high-rise apartment projects in southern China from the perspectives of medium, sensory, and treatment strategies. The analysis aimed to identify the areas in which the case projects could improve their defense against pandemics as well as to identify the areas where they may be lacking. In addition, the observation and analysis of the case projects provide insights into how the project should adjust the balance of the three pillars of sustainability. This analysis will help to ensure that projects are designed and implemented in a way that supports long-term sustainability, while also providing protection against pandemics.

3. Results and Discuss

The projects selected and analyzed in this study were four 33-storey high-rise residential buildings, which are typical high-rise apartment buildings in hot summer and warm winter regions. Figure 1 shows a bird's eye view of the project.

The project set the goal of "green building" at the beginning of planning, and the project won China's national green building two-star certification.

The technical route adopted in the design of the project in terms of green building technology is the use of light duct lighting in the basement, building vertical greening, solar hot water technology, and a high-quality miscellaneous drainage reuse and treatment system.

The technical route of the project tends to use equipment to statically improve the impact of buildings on the environment, such as energy and water savings and greening, but does not focus on the health of residents.



Figure 1. Bird's eye view of the project.

3.1. Analysis of the Design Strategy of Medium Strategies

3.1.1. Air

1. Wind environment

The overall ventilation of a residential area and the indoor ventilation of a building are directly influenced by the general plan and density of the community. Proper ventilation in residential rooms is effective in maintaining fresh and bacteria-free indoor air by using either natural or mechanical ventilation systems.

Improved air filtration can reduce the transmission of diseases, such as influenza, rhinovirus, tuberculosis, SARS, and the novel coronavirus. Properly controlling airflow between rooms can also help to prevent cross-infection. The planning and layout of apartment-style residential communities, including the density, building spacing, floor plan, apartment design, and door and window designs, can affect the ventilation environment, thus affecting the transmission of the virus. Yu et al. used CFD and a multi-region model to analyze whether there was a close relationship between the distribution of the infected population, the direction of air flow between floors, and the community wind speed field, indirectly proving the role of airborne transmission [26].

Wu et al. studied the spread of respiratory infectious diseases and used the CFDs method to assess the risk of cross-infection in a typical high-rise residential environment, focusing on transmission between buildings under wind action. The conclusion is that the risk of cross-infection between buildings cannot be ignored, especially when the number of infected people is high and the rate of pathogen production is high [27].

After the outbreak of COVID-19, Yuwei Dai et al. used the CFDs method to study ventilation in densely populated built environments and to assess the cross-diffusion of pollutants [28]. By analyzing fluid dynamics, they explained how the disease is transmitted between buildings using the wind environment. This shows the importance of building orientation. In the literature, the way wind, indoor/outdoor temperature, buoyancy, or chimney effects can promote disease transmission by connecting the amount of air shared by occupants of different units is described [19].

This paper analyzes the effects of planning layout, density, and building spacing on the ventilation environment using the computational fluid dynamics (CFDs) method to simulate and analyze the outdoor wind field distribution of the case project.

The PHOENICS2010 was used for the simulation and calculations. The project's outdoor boundary conditions were based on the climatic conditions of Nanning, which belongs to the south subtropical monsoon climate zone. Summer easterly winds were simulated with a wind speed of 1.65 m/s and a wind frequency of 7.7 percent, and northeast wind in winter with a wind speed of 1.4 m/s and natural ventilation under the action of 7.1 percent wind frequency. The upper part of the overhead floor is the main outdoor activity area of the community; so, the project mainly analyzed outdoor ventilation at a height of 5.5 m.

The wind speed vector diagram in Figure 2 illustrates the airflow at a height of 5.5 m during the summer season for the case project. As it can be observed in the figure, the wind speed is relatively low near the west building entrance, but there are no eddy current areas detected within the residential area. This indicates that outdoor ventilation is an effective means to eliminate waste heat and gas within the community, but there is still a risk that the virus will be carried by the wind from one building to another.

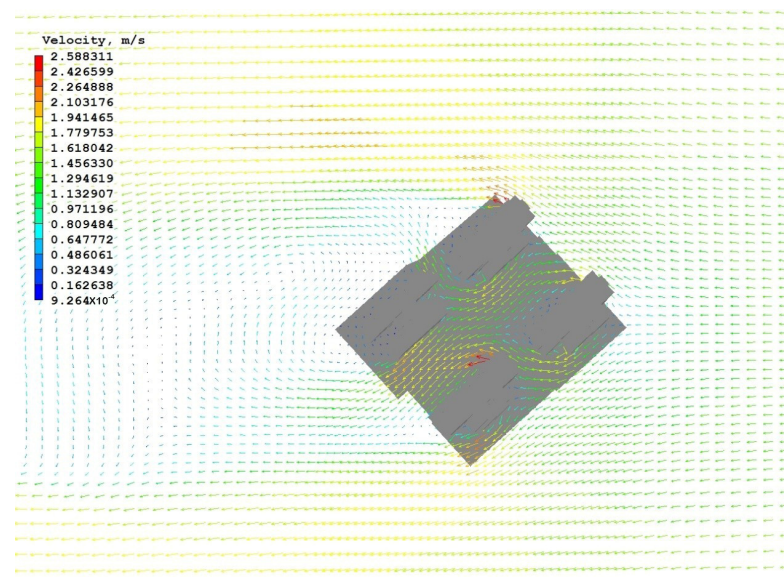


Figure 2. Wind speed vector diagram at an altitude of 5.5 m (due east of the summer wind direction).

Figure 3 displays the wind speed vector diagram of the case project at a height of 5.5 m during winter, when the wind blows from the northeast direction. The figure shows that the wind speed in the active area of the overhead floor is adequate due to the building blocking the northeast wind, while the wind speed in the southwest of the building is relatively low, but it does not significantly impact pedestrian comfort. However, the flow field's distribution is quite uniform around the building and the main entrance, with no eddy current or stagnant wind. However, there is still a risk that the wind's path could carry viruses and cause infection.

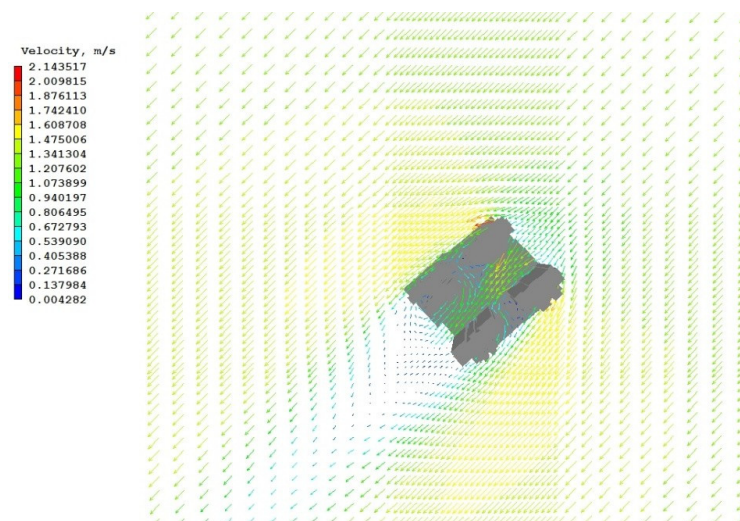


Figure 3. Wind speed vector diagram at an altitude of 5.5 m (winter wind direction: northeast).

Based on the simulation results of the outdoor wind field distribution, it can be concluded that the wind environment created by the general plan and design standards of the project is reasonable, and the overall ventilation condition is satisfactory. Although there is a risk of infection caused by viruses in the air stream, the impact is lower than that caused by indoor cross-infection.

2. Door and window designs

Figure 4 shows the wind pressure distribution on the windward side of the building under the condition that the summer wind direction of the case project is due east, and Figure 5 shows the wind pressure distribution on the leeward side of the building under the condition of the summer wind direction of the case project. As it can be seen in the figure, the pressure difference between the front and rear areas of the case project is essentially about 3 Pa. Such a large pressure difference between the front and rear areas can create a good indoor ventilation boundary condition.

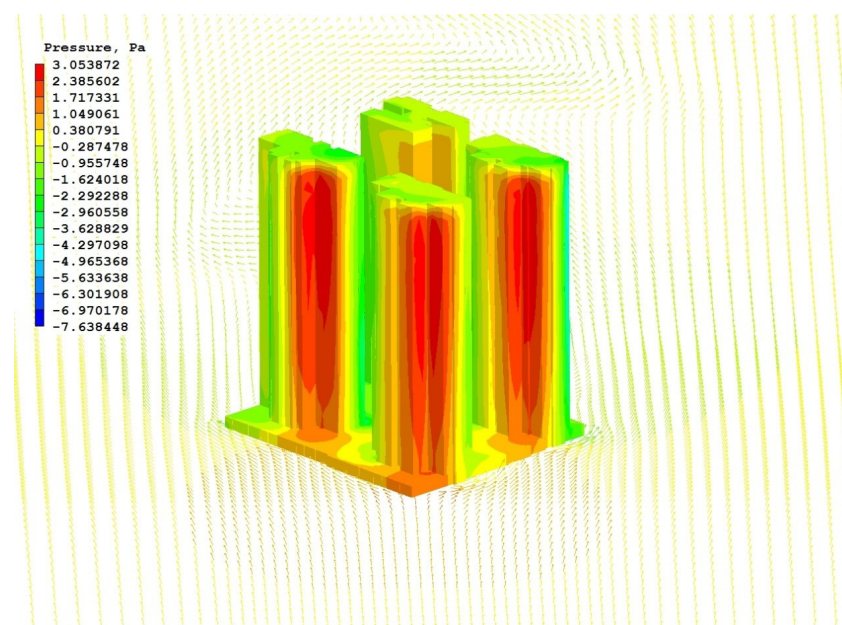


Figure 4. Wind pressure distribution map on the windward side of a building (due east of the summer wind).

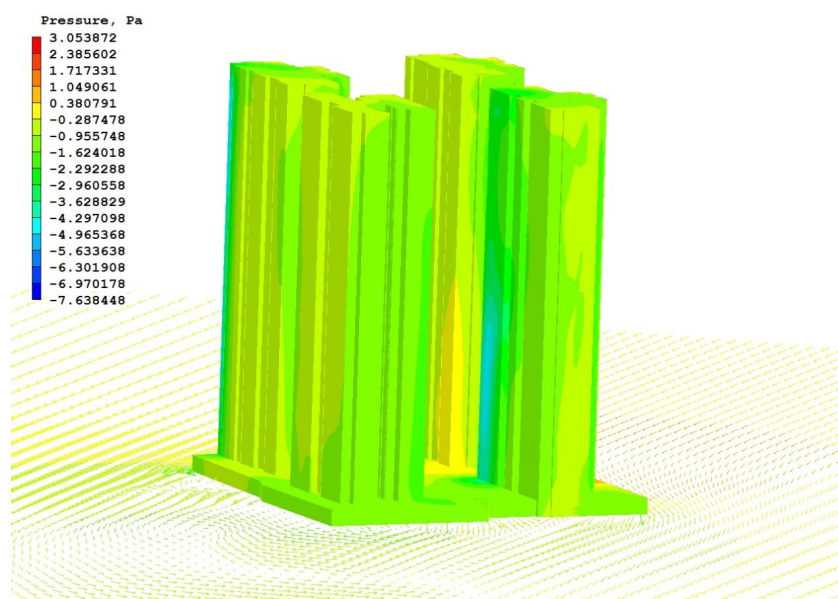


Figure 5. Wind pressure distribution on the leeward side of a building (due east of summer wind direction).

During the COVID-19 epidemic, although the airflow between buildings and the pressure difference between the front and back of the buildings may lead to the risk of virus infection, the infection caused by the close contact between family members was more frequent; thus, opening windows was still the best means of prevention, as far as was possible, to obtain fresh air. However, in the case of our project, the toilet and other areas can easily form a well when windows are closed, which leads to poor indoor ventilation and even the creation of the chimney effect of the pipe, leading to the infection of the upstairs residents. Therefore, property management is very important. The Chinese residential design standard requires that the opening area of doors and windows be $1/20$ of the room area and $1/10$ of the kitchen area; therefore, the doors and windows of the residential room of this project were $1/20$ of the room area. The opening area of each room only reaches the critical value of the design standard, while the doors and windows of high-rise residential buildings were selected to open flat windows at a fixed angle because of their safety and airtightness, and the area of window holes that can be opened is removed.

In the context of COVID-19, the first way to optimize rooms should entail changing the design of doors and windows to increase open areas and create a path of air flow.

The open areas of the room should be maximized so that the room can obtain as much outdoor fresh air as possible. At the same time, the path of air flow should be carefully designed to avoid the intersection of toilet air flow and a room's fresh air path.

In addition, many households can also add a household fresh air system with a purification function for the general fresh air volume to reach $200 \text{ m}^3/\text{h}$. Therefore, indoor air replacement can be achieved without opening windows, reducing the concentration of indoor particulate matter and ensuring a good air quality.

Households can also configure higher-grade air filters according to their economic conditions, increasing the proportion of air virus particles to 80 percent; portable air purifiers with high-efficiency filter screens (such as HEPA) can also be used for this purpose. It can not only avoid indoor cross-infections, but also prevent the outdoor air from carrying the virus.

In public spaces, because high-rise buildings generally adopt a core design, the epidemic prevention requirements of MURB are more complicated than those of single-family homes, because MURB usually has only one public service core, consisting of stairs, elevator rooms, entrance halls, and corridors. Every resident must enter the house through a public space, and how to address cross-infections in public spaces became a very difficult problem.

A property can only reduce cross-infections caused by pressing elevator floor buttons by increasing the frequency of elevator disinfection, hanging disinfectant in elevators, and by emphasizing specific measures, such as people wearing face masks.

Green building design standards place more focus on energy saving and environmental protection, but they ignore the impact of the environment and buildings on people. Therefore, the requirements of core tube ventilation and natural ventilation are not high. Future research should focus on the design of natural ventilation in public places.

In terms of floor plan, the front room of each elevator of the project is equipped with balconies and openable windows, which meets the requirement of the opening area of the front room of the fire elevator being no less than 2.0 square meters and that the front room shared with the smoke-proof stairwell be no less than 3.0 square meters. However, due to the core tube structure of the project, several households are crowded in the elevator hall; therefore, the exhaust window of the toilet still faces the elevator terrace.

As a result, the air exit route crosses the ventilation passageway in the public space of the elevator hall, which is not stipulated in the design standard.

The ventilation design essentially meets the epidemic prevention requirements, but the natural ventilation of the public space does not receive enough attention. The aspect of ventilation design is not in place, and the design standard is not high. As the structure of the building was already determined, only new ventilation equipment can be used to improve air quality, so as to adjust the impact of the building on the environment.

3.1.2. Analysis of Outdoor Wet and Hot Environments

Many viruses thrive in specific humidity environments, and controlling the ambient air temperature and humidity is crucial to prevent their spread. Influenza viruses, for example, can survive well in low-humidity environments, but studies show that the novel coronavirus has a higher survival rate under specific temperature and humidity conditions. Coronavirus particles may also enter the indoor environment from various emission sources with the help of environmental factors, such as relative humidity, wind speed, and temperature [29].

In this case project, the main area of activity for residents is on the overhead floor. To control the temperature and humidity levels, a water system and roof greening were installed. This is particularly important in Nanning, Guangxi, which is located in a hot and humid subtropical region. By creating a suitable hot and humid environment, residents are encouraged to participate in outdoor activities, improving their physical fitness and alleviating boredom during the COVID-19 epidemic.

However, modern cities in hot and humid areas often suffer from the heat island effect, which can have adverse effects on human health. Therefore, the project used PHOENICS 2010 to simulate the heat island effect to implement measures to mitigate its impact.

The simulation results are as follows:

1. As it can be seen in Figures 6 and 7, the surface temperature in the entire community was relatively low. The surface temperature of trees, water features, and wetlands is about 28–29 °C.

The grassland temperature of the district is about 30–33 °C. The outside of the district was assumed to be a cement floor, and its surface temperature is about 40–46 °C. The comparison reveals that, under the action of the waterscape, wetlands, tree greening, and grassland greening, the surface temperature of the district is much lower than that when there is no greening outside, indicating that the waterscape and greening of the district greatly reduced the heat island intensity of the district.

2. The ventilation of the district is smooth, and the internal heat of the district can be effectively excluded. The temperature is between 30 °C and 31 °C, which is only higher by 1 °C when compared to the temperature set by the outdoor ventilation of 30 °C. Compared with the air temperature of areas without greening and waterscapes outside the district, the temperature is also lower by 4 °C, which shows that the intensity of the heat island effect can be adjusted through reasonable landscape design.

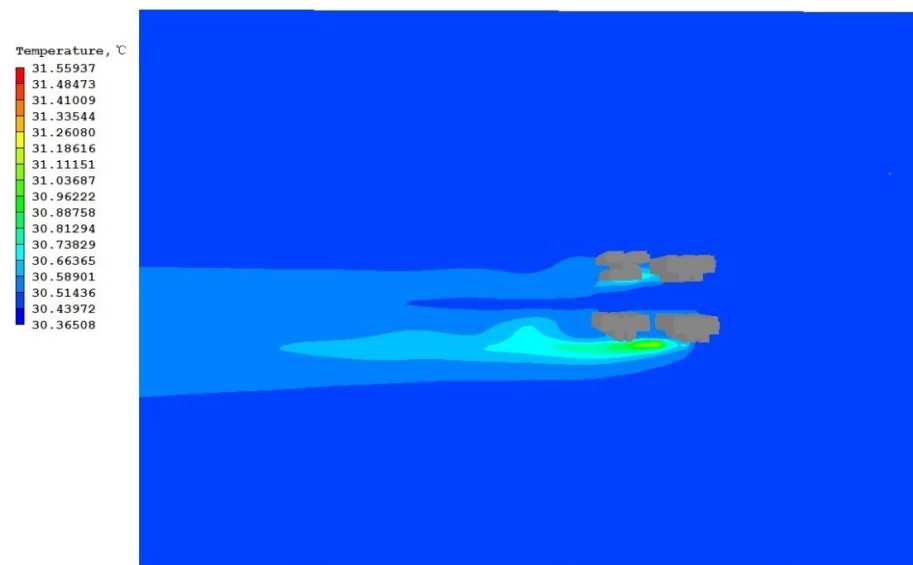


Figure 6. Cloud map of the temperature distribution at an altitude of 5.5 m above the ground.

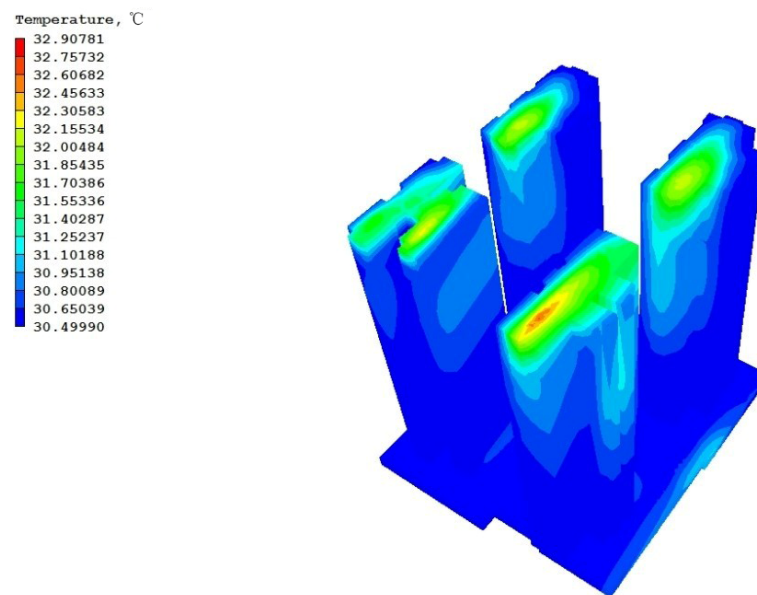


Figure 7. Cloud map of the temperature distribution at a height of 20 m above the ground.

Case project housing uses three-dimensional greening and roof greening technology. Limited investment can prevent the heat island effect and reduce the environmental temperature, allowing people to have the opportunity to engage in outdoor activities and enhancing their physical and mental health.

A suitable hot and humid environment that has localized plants and water systems creates a healthy residential microclimate. People can live in a balance in a pleasant microclimate; even if the community is closed, it can form a self-consistent ecosystem during the outbreak of an epidemic, which is important to guarantee the health of people in the community.

In addition, the indoor temperature and humidity of the environment are also very important. During the COVID-19 epidemic, in addition to enhancing indoor ventilation, people also used dryers and humidifiers to adjust the relative humidity of rooms, which can reduce the survival rate of the virus and simultaneously make the indoor environment more comfortable. To adjust the temperature of the residences in this project, a single air conditioner was used, but the external unit of the air conditioner was designed to be placed

under the floating window of the upstairs residents. When the upstairs residents open the window, there is a risk that the exhaust gas from the downstairs users will be mixed with the fresh air upstairs.

The case project adopted a greening design that was suitable for the local environment to control the temperature and humidity of the environmental microclimate, which has a positive impact on the environment and lays a good foundation for epidemic prevention.

3.1.3. Water: Water Supply and Drainage, and the Technical Analysis of Sponge Cities

Studies showed that the novel coronavirus can survive in water and sewage for a period extending from a few days to weeks [30,31]. As sewage may be the main source of the virus, more attention should be paid to the residential water supply and drainage design as well as water sources.

When COVID-19 broke out, people remembered the case of Amoy Gardens in Hong Kong, which faced an outbreak caused by the air flow between sewers. The analysis of the novel coronavirus communication incident in Hong Kong revealed that the risk of old high-rise buildings is large, and the mode of vertical transmission is evident [26]. The virus was suspected to spread mainly through public drains, and other facilities that spread along different floors, such as light wells, flue, and pipes, can also provide potential pathways [19].

Toilet flushing and floor drain failure scenarios are examples of potential hazards derived from fecal contamination. Aerosols of fecal-derived viruses can also be used for risk analysis in toilets [32]. If there is no ventilation for a long period of time, the concentration of viruses in the air may be significantly higher. It is important to note that existing indoor drainage systems, when used and maintained properly, are able to protect healthy residents from the pathogens to which they may be exposed. Therefore, strengthening property management is also very important for the maintenance of building pipelines.

As apartment buildings are usually multi-storey and high-rise buildings, the risk of vertical transmission is greater, and the openings of drainage systems, such as toilets and floor drains, are very likely to lead to aerosol transmission among floors.

Therefore, the design of drainage systems and various pipelines must specifically follow the following measures to prevent the spread of viruses.

1. The design of the water supply and drainage system

(1) Drainage and exhaust system

The floor toilet in the case project adopted a wall row-type, same-floor drainage system, which effectively avoids the problems caused by the horizontal drainage pipe of this floor entering into the lower space. It also has many advantages, including pipeline maintenance and cleaning being able to be completed on this floor without interfering with the lower floor; the drainage pipes of sanitary appliances do not penetrate through floors, and the arrangement of appliances is not restricted by structural features.

In addition, the outdoor drainage and chimney design can reduce the chance of cross-infections due to pipe leakage.

However, for cold areas during winter, pipe maintenance is especially important when the drainage pipe is designed to be indoors. The drainage pipe of the case project depends on the outdoors, but the chimney is indoors; therefore, there are potential risks.

Due to the continuous oil fume deposition in the kitchen flue, a large number of bacteria and viruses breed. As the flue valve inlet and outlet design used in the project was too simple and sealing was not enough, there is a potential risk of cross-infections occurring.

(2) Diversion of kitchen and bathroom

In the case project, drainage systems were set up in bathrooms and kitchens to avoid sharing drainage risers in these rooms. The horizontal mains in front of the outdoor drainage inspection wells were also set up separately to completely separate the drainage systems in

the kitchens and bathrooms. This procedure is of great significance, as during an epidemic period, it prevents the possibility of harmful gases flowing to their maximum extent.

(3) Other measures

Based on circumstantial evidence, the COVID-19 outbreak was possibly caused, in part, by fecal aerosol transmission. To prevent this spread, bio-aerosols can be controlled at the source by avoiding any potential leakage of gases from drainage systems into indoor spaces. For example, to prevent the spread of fecal aerosols, drainage traps (such as U-shaped traps) should not be dry [33].

After the COVID-19 epidemic, many household toilets were changed to prevent dry floor leakages, washing machines were protected against overflow floor leakages, and water seals were installed so that the depth was not to lower than 50 mm. Pipeline wells and equipment platforms used straight-through floor leakages. Sanitary appliances with water storage bends in the structure were used. The design also prevented the occurrence of air flow among floors.

Property management should inspect pipes regularly to prevent the spread of virus-carrying aerosols through pipes that are, for example, cracked or have loose joints.

2. Non-traditional water sources

According to the technical path of green building, the case project adopted sponge city technologies, such as rainwater recycling irrigation technology, in the high-rise residential district, constructed wetland water purification systems, favored off-grid solar photovoltaic power generation, water lifting, and greening irrigation, among others.

The rainwater reuse system used in the project entails the collection of roof rainwater to a rainwater collection pool through the rainwater riser and the outdoor rainwater pipe network of the community. The treated recycled water is used as greening, road, square, and underground garage flushing water, with the rest being discharged into the municipal rainwater pipeline.

However, in practice, the case project did not perform a good job in the monitoring of the water quality of the rainwater collection pool, and the water quality was poor, which led to mosquitos breeding in it. The use of the rainwater's landscape water system may also lead to the spread of bacteria. For non-traditional water sources, water supply systems should be equipped with an ozone disinfection device, and the water quality should be examined regularly.

Although the sponge city technology is an important sustainable development technology, if a system of water quality testing is not in place, the results may not be as desired.

3. Water quality monitoring

The community property of the case project did not formulate a water quality monitoring and management system, leading to the water quality being unknown and potentially polluted. A monitoring system should be established to effectively control the testing of the water quality and to ensure the quality and safety of all types of water supply. The timely examination of the water quality and its effective treatment prevents the potential negative impacts of substandard water quality on human health and the surrounding environment. In addition to a complete set of online monitoring of water quality at the outlet of the clear water tank of the rainwater reuse system, online monitoring equipment should be installed at the outlet of the water tank in the communal domestic pump room of the equipment, which can monitor for turbidity, residual chlorine, pH value, electrical conductivity, and other parameters whilst ensuring that the quality of drinking water meets the requirements.

4. Standby water sources

In order to prevent the interruption or pollution of the water supply in community wells, the rainwater collection system or other stored water can be used as backup water sources. Having a backup water source can ensure the water safety for the community. The water in the rainwater collection system used in the case project can be only used as a backup water source if water quality testing is performed.

5. Building and finishing materials

Residential door handles, elevator buttons, and other high-contact surface materials should be smooth, non-porous, and moisture-resistant to reduce the growth of bacteria and viruses. Therefore, materials on which bacteria and viruses cannot survive easily should be considered [34].

To achieve sustainability goals, building materials should be environmentally friendly, thus reducing the environmental impact of the construction industry; recyclable materials of those produced from renewable resources should be preferred, as well as those that produce low emissions and have low levels of volatile organic compounds (VOCs).

3.2. Analysis of the Design Strategy of Sensory Strategies

1. Acoustic Environment Analysis

To ensure a healthy soundscape, middle-aged and elderly individuals, who are susceptible to cardiovascular diseases and mental illness due to noise pollution, which is especially true during the COVID-19 pandemic, should be exposed to a healthy noise environment.

The case project is situated adjacent to a busy traffic trunk road in the west, resulting in high levels of noise. Specifically, the noise generated by trucks driving during the night disrupts the residents' sleep, affecting their health adversely. Figures 8 and 9 depict the noise simulation results obtained using the Cadana/A4.0 software.

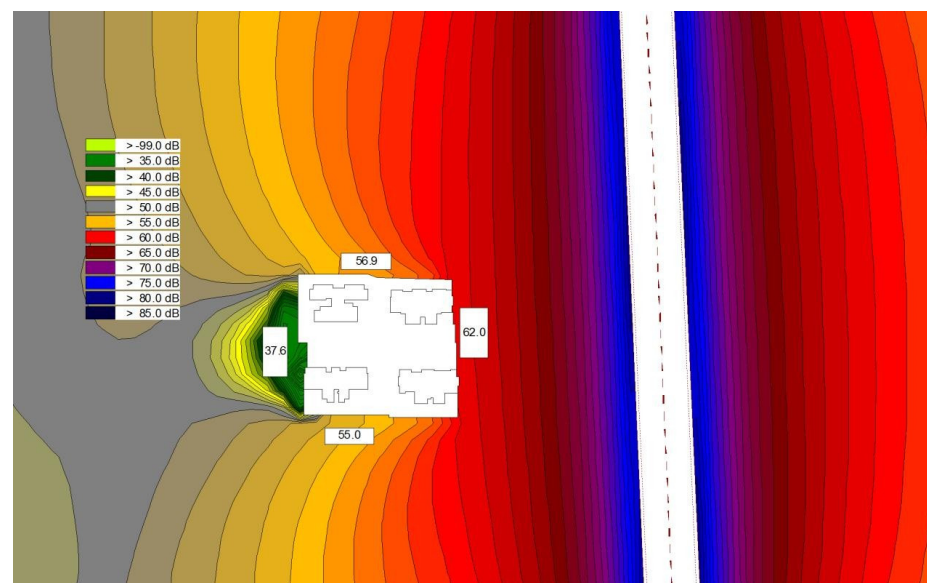


Figure 8. Distribution map of the daytime sound pressure levels in the residential area under analysis.

As shown in Figures 8 and 9, the noise in the area around the project is highly disturbing, exceeding the value required by the design specification.

In the design of the case project, no effective measures were undertaken to block the impact of noise. Due to the use of single-glazed glass windows, the impact of noise is greater. Therefore, roadside residents generally choose to close the windows to reduce the noise, resulting in poor ventilation and increasing the chances of bacteria and viruses breeding. Double glazing should be used in the design of doors and windows, as it can considerably block noise from coming into the house, and even if windows are opened, the influence of noise can be reduced accordingly.

In addition, there are many ways to block noise, such as setting a baffle on the path of the traveling noise or planting tall and dense trees to reduce noise decibel levels through its reflection by the baffle and the absorption of noise by plants.

Even if the cost of noise reduction measures is small, in most green building reviews, noise reduction measures are not adopted, because the noise analysis and simulation

software at this stage is not user-friendly and it represents additional workload for designers and an additional expense for construction units; however, for healthy communities, it is a necessary expense. The grading criteria of green buildings should increase the weight impact in this regard.

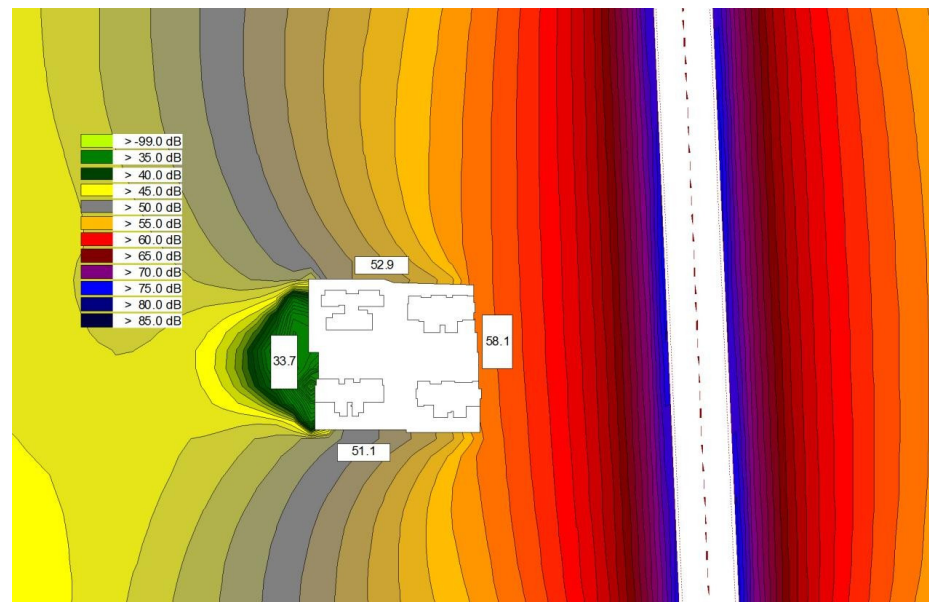


Figure 9. Distribution map of the sound pressure levels at night in the district under study.

2. Analysis of the light environment

A large number of studies showed that sunlight and proximity to nature have a positive effect on the health and well-being of families. People spend more than 90 percent of their time indoors and 70 percent of their time at home [35]. Especially in the context of a pandemic, sunshine can be the best at-home comfort.

The duration of sunshine is a very important indicator to ensure the quality of residential housing, and the sunshine standard should not be lowered for the sake of economic benefits.

Sunlight exposure causes a variety of photobiological reactions, thus enhancing the metabolism of humans.

The ultraviolet rays in sunlight can prevent and treat diseases, such as colds, bronchitis, tonsillitis, and rickets. People can also use the sun for heating and indoor disinfection so as to promote good sanitary conditions.

As all houses aim to have a high volume ratio of sunshine, we often receive requests for shortening the duration of sunshine in hot summer and warm winter areas. However, at present, when a virus epidemic may occur at any time, these requests are diminishing. The design standards of hot summer and warm winter areas in China require sunshine for at least 1 h in a cold day, on the basis of which the sunshine hours can be increased as much as possible to improve indoor comfort. Indoor lighting and sunshine are similar indicators, as direct lighting is an important factor for human daily life to maintain good health and a happy mood.

The case project under study was of the residential type. In the evaluation standard of green buildings, there is no need for a daylight analysis in the inner areas of residential buildings. However, due to unreasonable house style designs, some spaces do not obtain enough daylight, such as dining rooms, which is neither environmentally friendly nor healthy. In Figure 10, it can be observed that the main activity area of the household is the living and dining rooms at the back, and the lighting condition of the living room is poor, while the dining room only uses the lighting of the main entrance. According to the

living habits of modern people, doors are closed immediately, and the lighting of the entire dining room is almost zero.

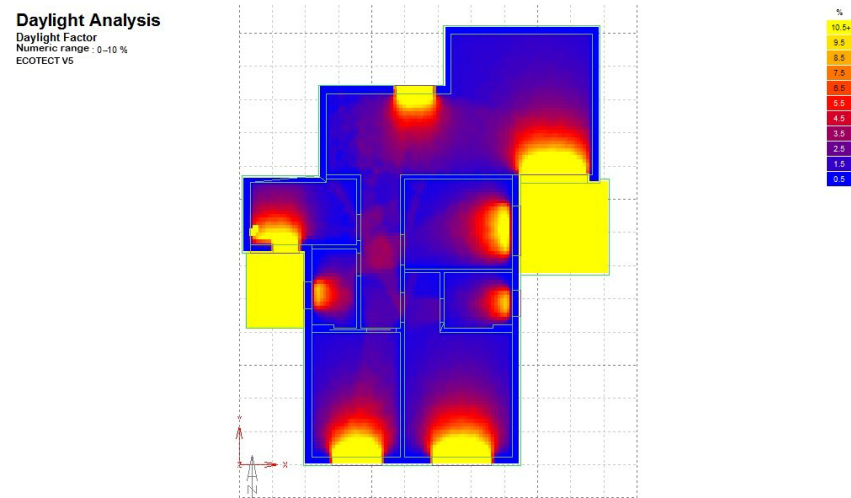


Figure 10. Household daylight analysis.

Under the rules of evaluation, designers often choose the option that is the easiest to operate and do not focus on the inhabitants. In the current evaluation standard of green buildings, the lighting requirements of residential buildings are worth discussing again.

During the COVID-19 epidemic, it is not advisable to open doors casually and venture outside. However, due to inadequate lighting, households are forced to turn on lights constantly. This results in a sharp surge in the power consumption. Furthermore, a prolonged lack of natural lighting contributes to people's low moods and emotional instability, further exacerbating the impact of the pandemic on their mental health.

3. Daylight and sleep aid design of regular day and night

To create a comfortable sleep environment, we need regular daylight and appropriate lighting, temperature, and noise levels. Daylight plays an important role in regulating our circadian regularity. Therefore, residential designs should not only ensure the provision of enough sunshine, but also uniform lighting, so that regular daylight can be obtained in all directions of the house. Technology can also be used to create a comfortable and relaxing sleep environment, such as simulating sound scenes such as oceans and forests. In the case project, many households only receive daylight on one side; this leads to uneven lighting.

4. Thermal comfort

Thermal comfort is an important index of residential physical environment evaluation, which is closely related to indoor thermal environment factors, such as indoor temperature, humidity, air flow, and the inner surface temperature of the enclosure structure. Thermal comfort affects the physical and mental health of residents.

First of all, the temperature, being too cold or too hot, causes people to feel negative emotions, such as anxiety and stress, and more importantly, it weakens the immune system, making it vulnerable to infections.

The second aspect of thermal comfort is ventilation. Good ventilation produces a comfortable body temperature, but the outdoor temperature being too cold and too hot makes people close doors and windows; thus, the design of mechanical ventilation is also very important.

Finally, an environment that is too dry or too humid causes negative emotions in people, affecting the mental health of indoor residents.

Therefore, thermal comfort is very important in the context of pandemics and needs to be carefully considered during the design step.

The outer structure of the case project is in line with the local energy-saving standard design. The inner surface temperature is suitable, the microclimate of the project can be adjusted by means of overhead layer greening, roof greening, three-dimensional greening, and other means, and the overall temperature and humidity are suitable.

The indoor temperature is mainly controlled by a single air conditioner, and the humidity is reduced by dehumidifiers.

3.3. Analysis of the Design Strategy of Treatment Strategies

The treatment strategies mentioned in this study refer to the technology adopted to achieve the purpose of epidemic prevention, the strategies aimed at promoting the development of healthy buildings, and additional technology on the basis of the orientation of the original building. These technologies can be scaled up or down based on project cost constraints, resident preferences, and epidemic severity.

Within this study, treatment strategies were identified from the literature and categorized based on their level of necessity:

- (1) Essential strategies: these encompass critical design measures that cannot be altered by the core structure of the building.
- (2) Enhancement strategies: these involve elements that enhance the user experience and are not indispensable for the basic functionality of the building.

3.3.1. Essential Strategies

1. Garbage disposal

The garbage refuse area is a breeding ground for germs. Unfortunately, the garbage disposal site for the case project is located in front of each building, which is an area with high foot traffic. Furthermore, it is not positioned in a location that intercepts the secondary spread of the epidemic. During epidemics, the garbage heap must be disinfected repeatedly to prevent the spread of diseases. To address this issue, a relatively dry area should be located, taking into account the prevailing wind direction, and garbage disposal equipment that features complete garbage classification and convenient disinfection should be established.

2. Reserve Energy Sources

Due to social distancing and quarantine requirements, people spend more time at home, which increases the demand for uninterrupted electricity. In the case of power outages, backup energy sources are crucial to maintain access to necessary equipment, such as heating and medical devices. The case project only has, at present, emergency power generation for the fire elevator, which is not sufficient to address the risks. Therefore, the project should consider installing backup energy sources for the entire building.

3. Contactless Technology

The COVID-19 pandemic accelerated the adoption of contactless technology to reduce the risk of virus exposure. The case project should consider upgrading access controls and sanitary ware to contactless systems, such as facial recognition or mobile access control. This will reduce the need for physical contact with potentially contaminated surfaces and help to maintain personal safety and hygiene.

4. Outdoor space design

The design of outdoor spaces should consider natural ventilation, organize ventilation reasonably, minimize the risk of air transmission, and integrate natural plants. Increasing the esthetic attraction of the area can help to purify the air and reduce health pressures. The outdoor design of the case project used the overhead space and carefully designed the green plants and water system through reasonable ventilation. The resulting environment is beautiful and pleasant. In addition, attention should be paid to controlling social distance, materials, and contact points to reduce the spread of the virus.

5. Balcony design

People who stay at home for a long time can suffer from feelings of isolation, stress, and anxiety. Balconies, which can provide fresh air, sunshine, and relaxation opportunities, are particularly important. The balcony can also provide a safe social space for friends, neighbors, and family; therefore, the view and orientation of the balcony are important. Due to the parallel layout of the balcony design in the case project, the two rows of buildings block each others' views; thus, half of the field of view of a balcony is the distance between the buildings, leading to a poor field of vision and insufficient resilience.

6. Reasonable foyer and public space layout with sufficient social distance

After the COVID-19 pandemic, the World Health Organization stated that a reasonable social distance should be 1.5 m or 2 m, and recently published studies supporting the assumption that the virus spreads more than 2 m from one place and that infected people are relatively safe [32]. From an architectural design perspective, the distance between people in this particular case should not become the space scale under normal, non-pandemic circumstances, but the space should be prepared to adapt this social distance when the specific circumstances arise. For public spaces to adopt this social distance, a larger structural span is required, and there is an urgent need to develop a structural system that matches these flexible spaces.

For apartment buildings, sharing public spaces is inevitable. The comfortable, safe, and free use of shared public spaces is very important for both communities and individuals. FITwel proposed the concept of "leveraging buildings to mitigate the spread of the virus" [36]. For public spaces, it involves implementing various strategies, such as limiting physical interactions, enhancing cleaning protocols, displaying hand washing instructions, improving ventilation and air filtration, and regulating humidity levels. This requires designers to have a more predictable design for the ventilation of public spaces, the adjustment of temperature and humidity levels, and a spatial structure that can flexibly adjust social distance.

7. Flexible interior spaces

After the COVID-19 pandemic, the concept of "home" was redefined: it is not only a haven for individuals to rest and the cradle of family affection, allowing us to achieve social isolation from viruses, but also enables people to work. Therefore, the future of home design may change accordingly [37].

This new function will produce a new form of space, which requires that the interior space is flexible so that the function of a "pure" home can be changed into a work, leisure, or learning space under certain conditions. A flexible partition space requires household design to create auxiliary spaces as far as possible, such as kitchen, toilet, pipe well and shear wall, and load-bearing column design, leaving a vast space in the middle for flexible partition or foldable furniture.

In addition, this new house style design should consider a relatively independent entrance hall, and the special area can be transformed into a space similar to an airlock to be used as a disinfection room. The most ideal scenario is to set up a balcony, which is open and independent, and can separate the entrance from the residential space in order to conduct disinfection.

According to the current building code, every household in a high-rise apartment building should have a shelter, equipped with fire doors, and have plenty of water and food. The shelter can consider using the master bedroom as much as possible, because the master bedroom, equipped with the main guard, can be used as a family isolation room, and patients will then have separate bathrooms and rooms, thus providing the possibility for family isolation.

8. Fire evacuation and isolation design

The case project under study is the residential community of Guangxi Architectural Scientific Research and Design Institute, a typical residential community with integrated

accommodation and offices. In the latter stages of the COVID-19 epidemic, many departments began to return to office buildings that were located less than 50 m away from the residence. This living mode reduced commuting times and the possibility of cross-infection in the commute.

However, the unclear streamline of office and residence increases the possibility of cross-infection. During an outbreak, the entrance to the community building should be transformed into an inspection post with protective capabilities, the lobby of the building should have the function and space of preliminary disinfection, and the residential unit should be able to set up a porch. Viruses can be comprehensively eliminated if “health”, as a basic attribute of the building and community, is considered during the entire process of planning, 745 design, construction, management, and transformation of buildings.

When an epidemic occurs, there should be a principle that epidemic management should not override fire evacuation, and isolation measures should not hinder fire evacuation. Taking into account social distance, fire evacuation design should take into account the area of the building, the number of residents, and the staircase and evacuation width, and organize a uniform distribution to all evacuation entrances and exits as far as possible to ensure the balance between social distance and evacuation time.

3.3.2. Enhancement Strategies

1. Fitness area

Due to the limited space available for the project, the main activity area in the residential zone is the overhead roof, which serves as a landscape greenery site. Unfortunately, the fitness area only consists of a single table tennis table, while the office area doubles as a basketball court and is often used for parking purposes. The options for exercise during epidemics are, therefore, quite limited. To encourage residents to adopt a healthy and ecological lifestyle, various fitness equipment and pedestrian pathways should be included on the floor overhead.

2. Humanistic construction

The project’s outdoor exchange site is located on the overhead roof and features gallery pavilions, seating, and a glass roof water system that provides parking lot lighting. The comfortable and cool environment fully meets the leisure needs of community residents. Additionally, electronic screens can be installed in public areas to keep people informed of the epidemic situation, which can help to dispel rumors and provide reassurance.

3. Smart community system

The intelligent community system collects residents’ information and health data through data, information, and network systems. The Internet and big data are used to release information in a timely manner and monitor the epidemic trends for telemedicine assistance.

As modern society becomes increasingly networked, the relationship between the community and the city should change from “relying on the medical and health system” to a “community-linked city.” To achieve this, the infrastructure for the intelligent community was established during the design phase of this project, with users being able to add facilities as needed. The original intelligent building equipment can be upgraded, and a whole-house information screen can be installed to monitor air quality, provide visual intercom, push information, and link security systems, thereby enhancing the linkage between residents, the community, and the city.

4. Landscape Design

Green vegetation has a healing effect on the mind and body, and natural elements, such as light, air, and vegetation, should be utilized to the fullest extent possible.

It is important to avoid dense green spaces, which can increase the risk of cross-infections. One of the technical paths adopted in the case project is roof greening and vertical greening. The case project designed multiple scattered rooftop gardens where residents can freely enjoy the sun and green grass.

5. Vertical Greening

In the context of the pandemic, residential communities should adopt decentralized green space planning, as a centralized green space concentrates the flow of people. As the case project is located in the center of the city, there is almost no land that can be used as greening; thus, the greening methods adopted by the project are three-dimensional greening and roof greening. Although the ornamental effect is good, the roof green area is limited; therefore, the per capita green area is too low. At the same time, the green space is too concentrated, and the risk of cross-infection is also high. Green spaces should be added to the floor elevator hall, residential balcony, walls, and other spaces to increase the area of vertical greening, so that people can come into contact with green plants anytime and anywhere to obtain comfort.

6. Self-Cleaning Spaces

Self-cleaning technology involves using advanced materials and coatings that resist dirt and bacterial growth. It can be used on frequently touched surfaces, such as door handles and sanitary ware, to minimize physical contact with potentially contaminated surfaces. The case project should consider incorporating this technology in public areas, such as restrooms, and replacing manually controlled sanitary ware to prevent infections.

7. Renewable Energy

The pandemic highlighted the importance of renewable energy in creating a sustainable environment and energy system. Renewable energy sources are local and not affected by supply chain disruptions. They also reduce air pollution, greenhouse gas emissions, and the risk of recurrent outbreaks. However, design standards for renewable energy equipment should not only focus on environmental benefits, but also consider economic benefits and people's needs. The case project should consider increasing the efficiency and utilization of the solar hot water system to reduce costs and promote usage.

8. Smart home

In the context of the COVID-19 pandemic, smart homes ushered in new development opportunities. Smart homes can be integrated with various home devices using smart speakers through voice or mobile applications, such as lighting, curtains, air conditioners, door locks, and security systems. Smart home devices should incorporate air quality monitoring systems that detect and remove harmful pollutants, which monitor temperature, humidity, and carbon dioxide levels to provide residents with a quality indoor environment. Installing UV-C lights in air conditioning systems or air purifiers can kill viruses and bacteria, including COVID-19.

In the age of the Internet, smart delivery and package management systems are especially important for apartment residential buildings, allowing contactless delivery and parcel segregation, ensuring the safety of occupants. The health monitoring system can measure signs such as heart rate, blood pressure, and body temperature, allowing occupants to monitor their own health conditions in the comfort of their homes, which may prevent the tragedy of sudden death caused by unattended patients suffering from new coronary pneumonia during self-isolation. A smart security system can keep your home safe with remote monitoring. The importance of the health role of the modern bathroom is increasing due to the social health awareness, leading to a need for independent health control and medical prophylaxis. Technologically advanced solutions, including IoT technologies, were reviewed and analyzed for health prophylaxis in home bathrooms. Innovative technologies offer the potential for easy information flow with the external environment, such as remote contact with healthcare professionals [38]. Smart home technology enables a convenient balance between functionality and security, providing a homely sense of security. The case project established the wiring and equipment of the smart home from the very beginning, which provides a good foundation for the achievement of smart homes. Residents can be equipped with dependent and capable equipment according to their own conditions, so as to achieve convenience and safety.

3.3.3. Summary

This study discussed 19 strategies, including 8 essential strategies, 9 enhancement strategies, and 2 quality improvement strategies.

The essential strategies deserve our attention. If they cannot be changed for structural reasons and cannot be achieved at the time of the outbreak, there will be one less means to resist the virus.

Developers and designers should fully meet these measures, which requires us to include them in the design conditions from the beginning of the design, thus requiring the adjustment of the corresponding design specifications. Otherwise, if the project is driven by costs and habits, these will be regrets in the future.

For enhancement strategies, developers and designers can consider their implementation priorities after evaluating the cost–benefit analysis according to the quality requirements of apartment buildings. As it does not involve structural content, it can be installed and used in time if necessary in the future.

Users cannot directly experience quality improvement strategies, but can save costs and improve construction quality at the same time; thus, developers and designers should try to implement these strategies and should have the courage to innovate and challenge new technologies.

4. Discussion

This study presented 47 design strategies that can be employed to make buildings more sustainable, including 9 medium strategies, 9 sensory strategies, and 29 treatment strategies. Of these design strategies, 17 positively impact the environment, 22 impact society, and 8 impact the economy. The aim of the paper was to achieve the balance of these three sustainability pillars.

When applied to a two-star green-certified building, eight of these strategies (17 percent) were already in place, including two medium strategies, four sensory strategies, and two treatment strategies. After applying the remaining 39 strategies, the number of implemented strategies increased to 27 (57 percent), including 7 media strategies, 2 sensory strategies, and 18 treatment strategies. Unfortunately, 12 strategies (26 percent) could not be implemented, including no medium strategies, 3 sensory strategies, and 9 treatment strategies.

Of the strategies that were implemented, five affect the environment, one affects society, and two affect the economy. The traditional green building technology, on which this study is based, focuses on environmental protection. However, the COVID-19 pandemic highlighted the importance of considering social and economic factors as well. Therefore, after the transformation, the number of strategies that can affect the environment increased to 12, while the number of social and economic strategies increased to 12 and 3, respectively.

Table 2 shows that, for medium strategies, the traditional green building approach emphasizes controlling air and water quality and building materials. To make these strategies more effective in preventing pandemics, modifications can be made to enhance their epidemic prevention function.

Table 2. Applicability analysis of the strategies.

Category	Implemented	Can Be Implemented	Cannot be Implemented
Medium	2	7	0
Sensory	4	2	3
Treatment	2	18	9
Total	9	27	12

For sensory strategies, the existing design measures of the case project focus on acousto-optic heat, sunshine, and daylight, which can be adjusted to improve defense against pandemics. However, ventilation standards need to be made stricter, which requires changes in graphic and structural design.

For treatment strategies, traditional green building technology tends to prioritize environmental protection over health concerns [39]. Healthy buildings should be designed and built according to people's health needs [40]. Many green buildings one-sidedly focus on indoor indicators and green technology [41]. There is no zero-contact system, purification system, and defense adjustment system built around the health of residents; thus, it is impossible to address extreme situations.

Despite these limitations, the existing design measures benefit from the traditional green building's emphasis on environmental protection and the proper control of sound, light, heat, and other environmental factors. Moreover, the high proportion of design measures that can be implemented after transformation reflects the good foundation that traditional green buildings laid for sustainable development.

The design strategies that could not be implemented indicate a lack of foresight in general planning and design, as well as in the lack of attention to healthy buildings. As pandemics are sudden and unconventional events, the design strategies adopted should focus on measures that can be implemented on the basis of the original design, provided that the building has a good foundation for addressing extreme situations.

On the other hand, COVID-19 brought opportunities and challenges to many aspects of society, such as health care, health, food, and tourism [42]. Healthy buildings should meet this challenge.

Adjustments need to be made in the overall planning of wind environment and heat and humidity environment design, sound, light and thermal environment regulation, public space and interior design or public health, equipment and pipe wells, door and window design, and many other aspects around the health of residents, in order to maintain the sustainable development of healthy life in the community. How to achieve this adjustment cannot be solved by piling up various technical measures. After analyzing the measures one by one in specific projects, we found that the green building system places too much emphasis on environmental protection and energy saving. There is no people-oriented defensive and healthy building system. This requires a sufficiently flexible structural system.

Therefore, some defensive measures cannot be implemented in existing green buildings. Only by giving importance to the values of healthy buildings and adjusting design standards to a universal and inclusive design can we face the threat of pandemics. Awada also pointed out that more work needs to be conducted in the future to establish common design standards to assess how buildings are designed to support health and well-being, and attitudes towards healthy buildings are the key [43].

Through an analysis of the impact of COVID-19 on the sustainable development of apartment buildings, we identified opportunities for transformation towards sustainability. For instance, instead of solely focusing on technology and indoor metrics, we can shift the emphasis towards discussing overall health to foster the growth of healthier housing options. This includes considerations for the health of public spaces, lifestyle changes, and the need for more comprehensive family living spaces.

The present moment presents an optimal opportunity to advance the development of health-conscious buildings within our social and technological systems. As a result, it becomes imperative to prioritize residents' health as the foundation of sustainable development. This entails the creation of building designs that are more adaptable and flexible, and capable of responding effectively to unforeseen events, such as pandemics.

5. Conclusions

From the analysis of the data, it becomes evident that the green building design system indeed laid a strong foundation for sustainable development. This is apparent through the primary acousto-optic and thermal environment analyses, with a noteworthy finding that 57 percent of the design measures can be applied to existing green buildings following renovation. However, the COVID-19 pandemic shed light on the limitations of today's green buildings in safeguarding public health, emphasizing the urgent need for healthy building solutions.

Among the 12 design strategies that could not be implemented, examples include the need for structural and auxiliary space adjustments to accommodate flexible apartment layouts and ensuring that public spaces adhere to appropriate social distancing guidelines, such as not being overly long and narrow. The crux of the matter lies in the absence of a comprehensive and flexible healthy building system.

Traditionally designed green apartment-style residential buildings excel in creating comfortable and environmentally friendly living environments. However, as society evolves, housing takes on multifaceted roles, and people's lifestyles shift toward more flexible and adaptable spaces. The demand for public spaces that cater to diverse needs and flexible utilization became increasingly pressing, necessitating their inclusion in a holistic healthy building system.

The pandemic glaringly exposed the inadequacies of conventional green building practices in both ecological defense and adapting to future lifestyles, underscoring the need for a comprehensive healthy building system. Buildings should prioritize the well-being of occupants over green technology itself. This study aimed to uncover why many of the design strategies discussed in the literature fail to mitigate the spread of COVID-19 and highlighted the scarcity of studies evaluating the feasibility of these strategies in existing structures.

Through a detailed analysis of the applicability of each design strategy in real-world case studies, a clear message emerges: China's green building system places excessive emphasis on energy efficiency and environmental protection, lacking a robust healthy building framework. Consequently, many measures remain unattainable in existing structures, leading to the inability to establish timely contactless, purification, and defense adjustment systems during pandemics. It lacks sufficient comprehensiveness and flexibility.

COVID-19 is an enduring extreme event, and a healthy home need not remain in a constant state of defense. Instead, housing designs should demonstrate foresight by providing adaptable foundations for unforeseen needs and aligning with housing development trends. A healthy home should serve as a basis for implementing various measures during extreme events, ensuring the long-term physical, psychological, and social well-being of residents. When crises such as pandemics strike, with the foundation established earlier, quick adjustments can be made by incorporating various measures and equipment to safeguard residents' lives, transforming healthy homes into fortified havens. This embodies the essence of healthy housing for sustainable development.

The limitations of this study include the representativeness of the project being limited to China and the need to summarize more comprehensive design strategies. Nevertheless, we still hope to obtain valuable insights to promote the sustainable development of housing.

Through an analysis of evolving design strategies in Chinese typical green high-rise residential buildings in hot and humid subtropical regions in the post-COVID-19 pandemic era, this paper unveiled the shortcomings of green buildings and underscored the imperative need for sustainable and healthy buildings that are anchored in residents' well-being and ready for timely adjustments during crises. It offers feasible design ideas for the post-COVID-19 pandemic era and to encourage the sustainable development of housing.

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