

On the Ventilation Layout Pattern of Buildings to Reduce the Risk of Transmission of Respiratory Infectious Diseases from the Perspective of Healthy City: The case of Wuhan Community

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Abstract

This study focuses on the Wuhan community and examines the significance of architectural layout in the development of healthy cities. The aim is to establish an architectural ventilation layout model conducive to reducing the risk of respiratory infectious disease transmission. By amalgamating infection occurrence of illness data and simulating environmental conditions, the effectiveness of optimized ventilation layouts in reducing transmission rates was validated. Concurrently, in conjunction with simulation outcomes, a natural ventilation architectural layout scheme conducive to mitigating virus transmission was proposed. Grounded in the perspective of healthy urban development, this research employs computational simulations and other methodologies to propose a practical approach towards reducing transmission rates, specifically from the vantage point of ventilation layout.

Keywords

Novel Coronavirus; Demand-driven Ventilation Methods; Architectural Layout; Healthy Buildings; Wuhan.

1. Introduction

1.1. Healthy Cities

A healthy city is a concept that was first introduced in 1984 and then officially defined by the World Health Organization as a city that is constantly developing, expanding its natural and social environment, expanding its social resources, and enabling people to support each other in the enjoyment of life and the realization of their potential. Its core lies in the organic whole composed of healthy people, healthy environment and healthy society. It is the key to building a healthy living environment by Urban planning and construction.

Globally, the development of healthy cities continues to advance, with China joining in 1994 and launching pilot programs in Suzhou and Shanghai, gradually expanding to more cities. The latest "Healthy China 2030" program outline proposes to build a number of healthy cities, villages and towns by 2030. Especially after the outbreak of the new coronavirus, the impact of respiratory infectious diseases on the physical and mental health of urban residents has been highlighted as one of the important factors hindering the development of urban health, and healthy urban planning and space has become an important research direction. [1] This study aims to provide guidance for the construction of healthy cities in the future by studying the impact of building ventilation layout patterns on the spread of respiratory diseases.

1.2. Project Background

Wuhan government has taken active response measures in the prevention and control of the new coronavirus. While comprehensively testing for the new coronavirus, it emphasized community

work, strictly screened and quarantined, and rigorously recorded the number and location of new infections each day, and continued to improve and formulate the "New Coronavirus Pneumonia Prevention and Control Program," effectively controlling the expansion of the scope of the infection. At the time of the rapid spread of the virus, Wuhan adopted precisely preventive and controlled measures to isolate the buildings where confirmed occurrence of illness and close contacts were located, and quickly controlled the epidemic, accumulating rich experience in the prevention and control of the virus. [2]

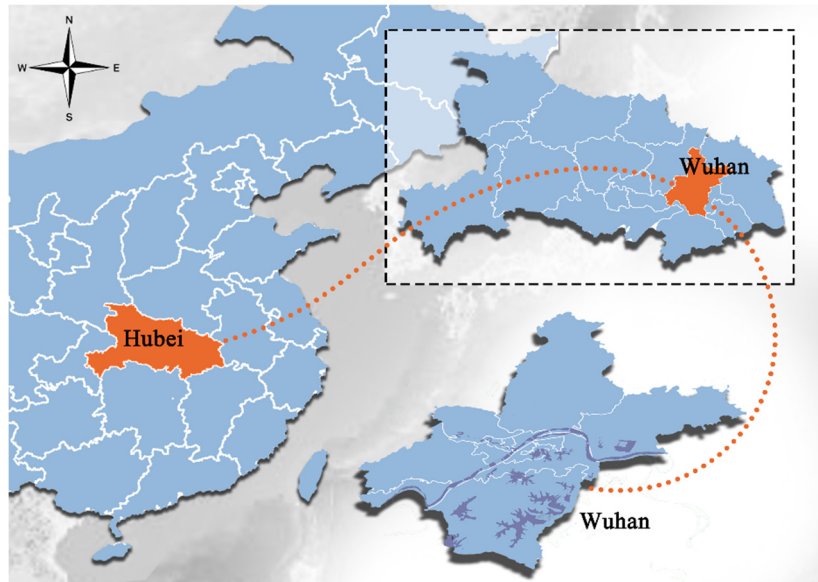


Figure 1. Location map of the research object

In-depth exploration of the transmission mechanism of the new coronavirus, found that its transmission pathways include droplets, direct contact and possible aerosol transmission [3]. The period of lockdown was chosen as the main source of data for the study in order to exclude the interference of other potential infection factors and to observe more clearly the influence of building ventilation factors on virus transmission. During this period, people's activities were mainly restricted, spending most of their time in centralized buildings, making the effect of building ventilation factors on virus transmission more significant, thus ensuring the scientific validity and rigor of the study.

1.3. Research Objectives and Methods

Aiming at the development of healthy cities and the establishment of healthy living areas, the study will explore building layouts that help reduce the risk of respiratory infectious disease transmission from the perspective of ventilation. By analyzing the infection data during the closure and control of the new coronavirus in the old communities in Wuhan, we screened representative Wuhan communities, combined with the green energy-saving software - Swire Building Ventilation VENT2023, to analyze the relationship between the building layout and the virus transmission, and explored better building layouts in the Wuhan communities in which the natural ventilation impedes the transmission of the virus. The methodological process is as follows:

I. Based on the infection data of the last quarantine cycle with numerical records before the closure and control in January 2023, we analyzed and studied to screen out representative communities: one is the positive occurrence of illness community with less number of people infected with the virus during the closure and control period; and one is the negative occurrence of illness community with more number of people infected with the virus and pneumonia during the closure and control period;

II. Based on the climatic characteristics of the urban environment and the dominant wind direction, we constructed a community model from the data analysis, and simulated the wind environment of the community scale coupling by CFD hydrodynamic computation, so as to derive the influence of different building layouts on the spread of the virus;

III. Examine the relationship between building layout and the spread of infectious diseases through wind environment simulation, and make targeted suggestions to improve building ventilation based on the system guidance and Wuhan community simulation results.

The main purpose of this study is to explore the building ventilation layout to reduce the risk of respiratory infectious diseases in Wuhan, and to actively promote the establishment of a healthy living environment and a healthy city.

2. Screening and Analytical Power and Reflection of Research Subjects

Considering that the incubation period of novel coronavirus is 15 days and the end of Wuhan's quarantine on December 8, 2022, the study selected the number of newly infected occurrence of illness in Wuhan from November 24, 2022 to December 8, 2022 and the location information of the communities in Wuhan as the study data. Communities with a large number of new viral infection occurrence of illness within 15 days and new infection occurrence of illness occurring on multiple days and communities with no new infection occurrence of illness within one isolation cycle after the emergence of new infection occurrence of illness on November 24 only were taken as the study objects to establish a basic database of information on new infection occurrence of illness in the community. The database includes the number of asymptomatic infected occurrence of illness per day, the number of confirmed occurrence of illness, the information on the resident areas and specific locations of infected occurrence of illness, and the centralized isolation of infected occurrence of illness. Combined with data screening methods, the database was screened and analyzed at three levels of classification.

2.1. Results of Data Analysis

I. Results after screening by primary classification

The data on the number of new occurrence of illness of new viral infections per day and home address information on November 24 were processed to screen out the community streets with no new infections after the emergence of new infections on November 24 only.

II. After screening for secondary categorization

Communities, streets, and neighborhoods with ≥ 2 new occurrence of illness records on the same day were screened for secondary categorization to obtain communities, streets, and neighborhoods with new occurrence of illness on 2 and more days. It was analyzed as follows:

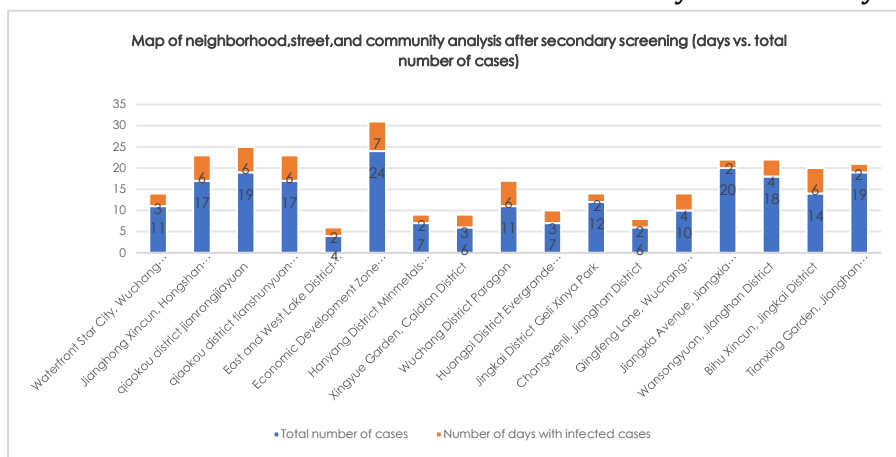


Figure 2. Total number of occurrence of illness and days with occurrence of illness in neighborhoods, streets, and communities after secondary screening

III. Tertiary categorization of screening results

The results of the primary and secondary screening were analyzed to obtain the communities, neighborhoods, and streets that had a higher number of new infections occurrence of illness and a longer number of days with new infections occurrence of illness. The figure below.

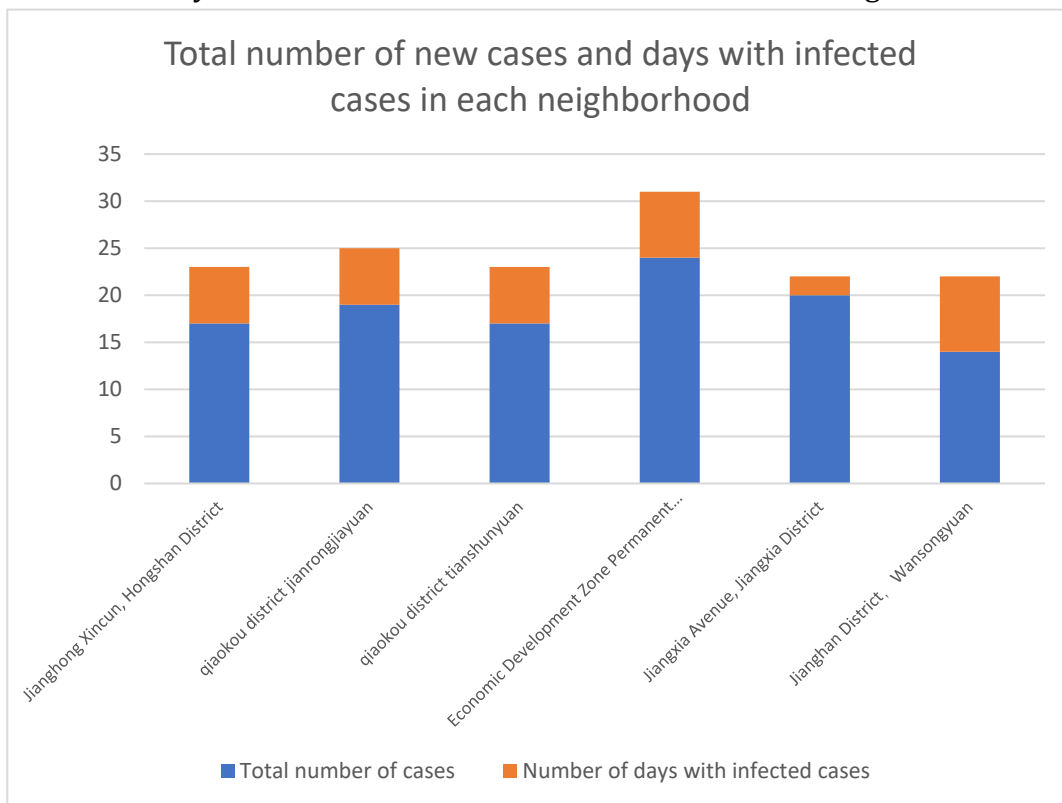


Figure 3. Total number of new occurrences of illness and number of days with occurrence of infection occurrences of illness in each cell from November 24, 2022 - December 8, 2022

3. Wind Environment Simulation for a Typical Community

Building spacing has been shown to be a crucial factor when studying the spread of infectious diseases. Excessive spacing can be effective in reducing the risk of virus transmission, as confirmed by the study of P. Chen et al. However, too little spacing may increase the risk of horizontal cross-household transmission of infectious diseases in high-rise residential buildings [4]. At the same time, narrow building spacing may interfere with the wind environment outside the building, which further affects the mechanism of virus transmission.

Adequate fresh air volume appears to be critical in the software simulation component of modeling the wind environment. Li Wenpei's Studies [5] have pointed out that a fresh air volume of 30 m³/h per capita is generally considered to be the standard for effective dilution of pollutants. Therefore, natural ventilation systems must meet this criterion in their design and operation in order to guarantee an adequate supply of fresh air and thus effectively reduce the potential risk of its transmission.

At the same time, wind speed and pressure also have a significant impact on virus transmission. Studies have shown that high wind speed contributes to higher rates of airborne virus transmission because it has the potential to create low-pressure zones that are conducive to airborne transmission of viruses [6]. This will be further explored in the simulation process to fully understand the mechanism of the wind environment on virus transmission in a typical community in Wuhan.

In the software simulation, many of the above factors are considered in detail to present the simulation results of the wind environment of a typical community in Wuhan on the spread of viruses, and to provide a more in-depth scientific basis for dealing with the spread of infectious diseases.

3.1. Research Process and Usage

In 2004, the first set of green building standards in China. "Research on Green Building Standards and Evaluation System" was successfully accepted and widely used in engineering and construction, green building as a newer construction model has received widespread attention in China's construction industry, and its evaluation and calculation system is becoming more and more mature. As a green and energy-saving software that runs on a CAD platform and adapts to all kinds of building forms, Swire Building Ventilation VENT (hereinafter referred to as VENT) can simulate the wind environment of a building, and its operation steps are adapted to the current architects' design software, so it is a ventilation analyzing software that is more commonly used in China. In this study, we employ VENT to simulate the wind environment in representative communities resulting from data analysis. We employ artificial intelligence mapping to delineate building complex outlines, incorporating drawing outcomes and building heights into VENT2023 for comprehensive modeling. This approach allows us to assess the effects of diverse building layouts on virus transmission and, subsequently, to propose natural ventilation strategies for mitigating virus propagation and optimizing building layouts..

Wuhan has a subtropical monsoon climate with hot summer and cold east. According to the Design Code for Heating, Ventilation and Air Conditioning of Civil Buildings, the wind speed and direction in Wuhan are selected as shown in Table 1 below. Since the screening time of the data of the infected people with new coronary pneumonia is winter, this paper adopts winter NE 3.0m/s as the boundary condition for simulation and analysis.

Table 1. Performance Comparison

Season	Wind speed (m/s)	Wind direction	Wind direction (°)
Winter	3.00	NE	45.0

VENT software uses CFD (Computational Fluid Dynamics) method to solve the wind field, i.e., to establish the conservation of mass, momentum and energy of the fluid flow to establish the mathematical control equations in the analyzed computational domain [7] , whose general form is shown below:

$$\frac{\partial (\rho\phi)}{\partial t} + \text{div} (\rho U\phi) = \text{div} (\Gamma_{\phi} \text{grad}\phi) + S_{\phi}$$

Meanwhile, the following formula is used for the average wind speed (reflecting the amplification of wind speed by high-rise buildings, which usually refers to the ratio of the maximum wind speed at a height of 1.5 m above the ground around the building to the wind speed at the same height in the open area.) The exponential function that varies with height is used for the calculation of the wind speed amplification factor.

$$\begin{cases} V_{1.5f} = V_{10f} \left(\frac{1.5}{10}\right)^{\alpha} \\ V' = \frac{V_{1.5B}}{V_{1.5f}} \end{cases}$$

included among these:

V' --Wind speed amplification factor;

$V_{1.5B}$ --Maximum wind speed around the building at a height of 1.5 meters from the ground, which is obtained by the aforementioned wind speed calculation and corresponds to the data in the wind speed cloud at a height of 1.5.

$V_{1.5f}$ --Wind speed at a height of 1.5 meters from the ground in an open area away from the building.

V_{10f} --Wind speed at a height of 10 meters from the ground in the open area away from the building, where the wind speed at the entrance boundary of the outdoor wind farm is taken.

a – Ground roughness index, this project is 0.28.

3.2. Simulation Results

The community data obtained from the "screening and analysis of research objects" in the paper were imported into the VENT software, and the results of the analysis were studied, and the author organized and classified the ventilation of the representative analysis results, and obtained the following contents.

I. Communities where the virus spreads at a slower rate and natural ventilation has a strong impediment to spread.

This type of community was selected as a positive case of ventilation with strong obstruction to virus transmission by only the wind environment wind pressure cloud map of the community with new occurrences of illness on November 24, and its ventilation advantage was analyzed, and it was found that the lower building density (or the farther distance between the buildings) and the main functional rooms (the rooms with a long time of use, for example, the bedrooms and the living room) opening the windows to the low-pressure area had a negative impact on the Virus transmission has a negative impact.

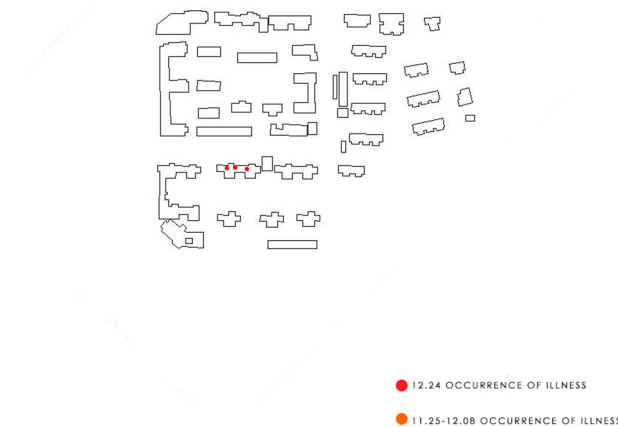


Figure 4. Waterfront New Town

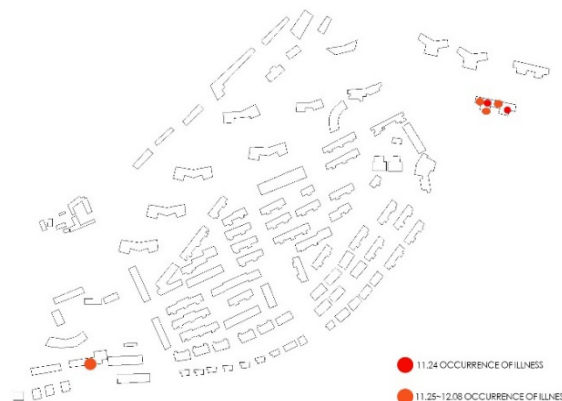


Figure 5. Derma Holiday

a. Building density and building spacing

The neighborhoods represented by Waterfront Star City and Derma Holiday are cases where large building spacing leads to low transmission rates. Existing in the Waterfront New City ABC zone phase Qin Yuan Road and Qixing Road, the regional spacing is large, so it failed to complete the transmission of the inter-area. The strategic placement of the infected unit in the district's outermost region, within the downwind low-pressure area, plays a pivotal role in preventing the virus from spreading within a fifteen-day timeframe. Similarly, at Derma Holiday, the infected unit benefits from ample building spacing on the north and south sides of the complex, effectively hindering virus transmission.

b. Orientation of window openings in major functional rooms and wind direction

Wind pressure ventilation is one of the important driving forces of natural ventilation, which has a simple and easy-to-understand principle. After the natural wind is blocked by the building, positive wind pressure will be formed on the windward side of the building, and negative wind pressure will be formed on the leeward side. At this time, the formation of the wind pressure difference will provide power for natural ventilation. Under the analysis of the wind environment of the building complex, the direction of the window openings of the main functional rooms of the infected units of Hongfu Homes, Mingshi Homes and Menghu Lake Community is a low-pressure area, and the flow of air with viruses to the other building units is less likely to occur, so the wind-pressure difference becomes a natural viral barrier, hindering the dissemination of the new coronavirus.

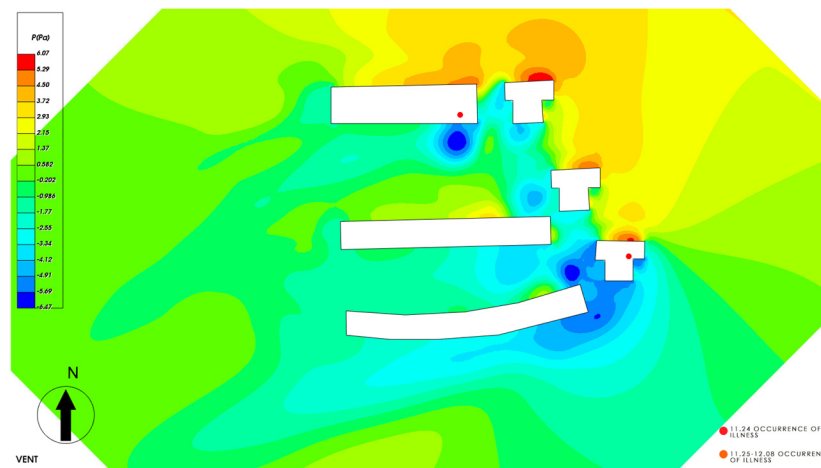


Figure 6. Hong Fook Homes

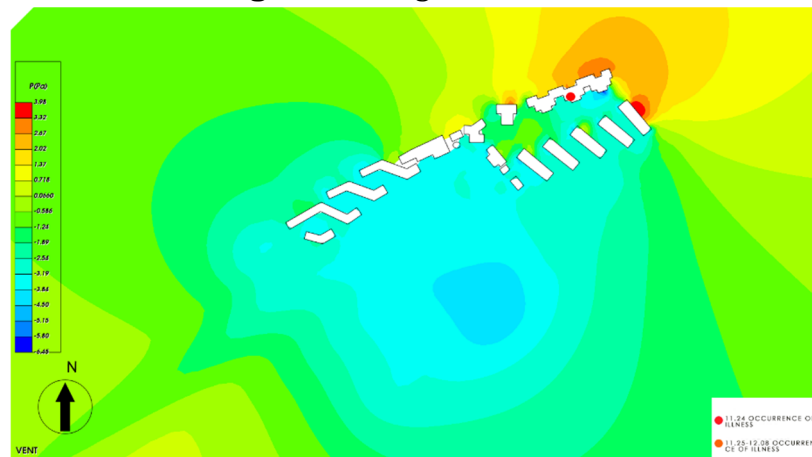


Figure 7. Dream Lake Waterfront

II. Virus transmission rate is faster, natural ventilation has a weak hindering effect on the spread of community

This type of community selected the wind environment wind pressure cloud map of the community with a high number of new occurrences of illness and a high number of new days from November 24 to December 8, 2022, as a counter case of ventilation with a stronger impediment to the spread of viruses, and analyzed its building layout, and found that a high density of the building, double-sided windows in the main functional rooms [8] or windows to the high-pressure area were the the reason for the higher virus transmission rate.

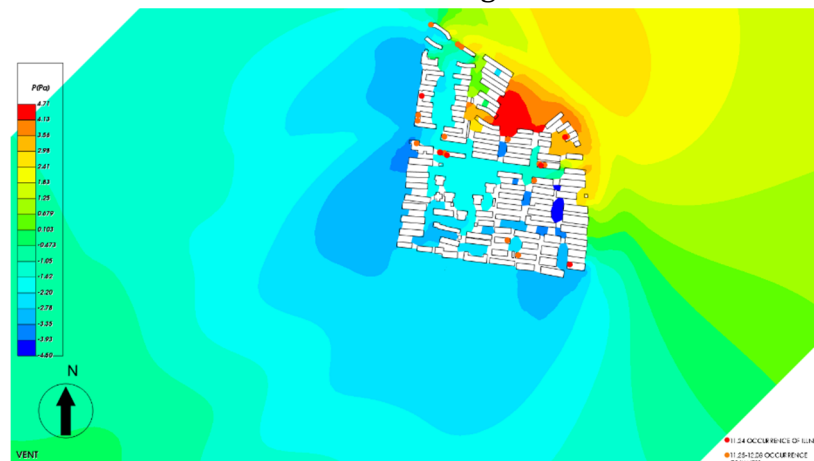


Figure 8. Tianshun Garden

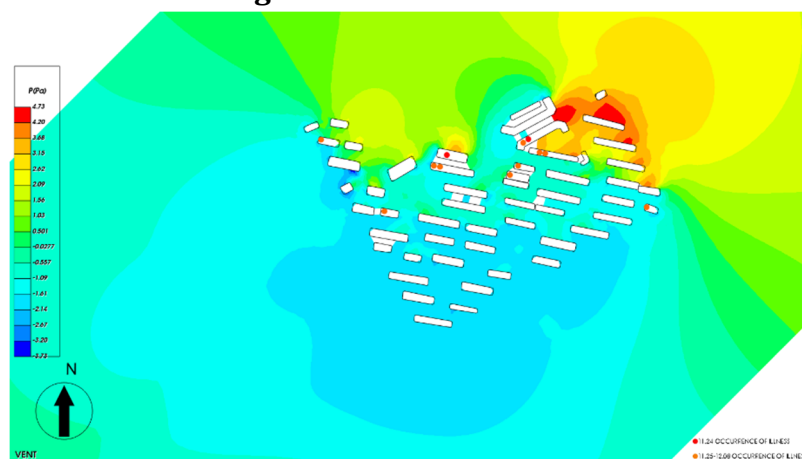


Figure 9. Permanent Community in the Economic Development Zone

For example, Tianshun Park and the permanent community in the Jingkai District, this type of community has a high building density, while some of the infected units have main room openings on the south side of the building located in high-pressure zones, and there is a possibility that air with viruses will flow to other building units, which led to a higher infection rate during the closure and control period.

Based on the above studies, analyses and investigations, it is concluded that there are certain effects of building layout on virus transmission. This paper attempts to use these effects to propose building layout optimization strategies to provide assistance in the architectural perspective of virus or influenza prevention and control needs.

3.3. Analysis and Recommendations

In order to guide the development, assessment and standardization of building energy efficiency and green building work in Hubei Province, the Hubei Provincial Department of Housing and Construction issued the Hubei Building Energy Efficiency and Green Building Standard System (2022 Edition) (hereinafter referred to as "the system"), which deeply promotes the development of green building scale and quality. In this context, based on the guidance of the

system and the status quo of Wuhan's old neighborhoods, the author puts forward suggestions to improve building ventilation.

1. Avoid two-way window openings in major functional rooms

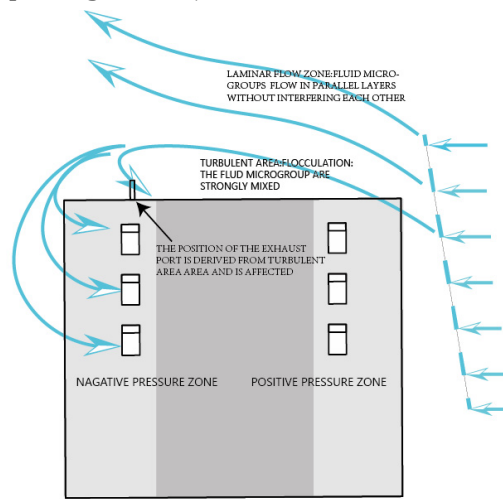


Figure 10. Building pressure flow

As shown in Figure 10, the negative air pressure zone of high-rise buildings is significantly higher than the roof of the building [9], and even if the height of the residential exhaust pipe is raised, it still cannot prevent the wind that passes through the infected units in the high-pressure zone from blowing the virus to the occupants in the low-pressure zone. Taking Wuhan as an example, the author suggests opening the windows of the bedroom, which is the main function room with a longer use time demand, to the south direction (the low pressure side of the back wind), and opening the windows of the dining room and study, which is the secondary function room with a shorter use time, to the north direction (the high pressure side of the wind). This layout not only creates a more comfortable sunlight and ventilation of the main functional space, and for the infected unit, the non-main functional space of the utilization rate is low, so in the high-pressure area will not have too much residual virus flow to the low-pressure area of the building complex. Here, the author believes that we can consider the layout of the residential complex sitting in the north-south layout, which can form a natural wind pressure barrier in the window surface, not only for the blocking of viral demand can also provide favorable help, but also to meet the system of "appropriate use of north-south appropriate orientation layout" of the building planning and layout recommendations. (As shown in Figure 11)

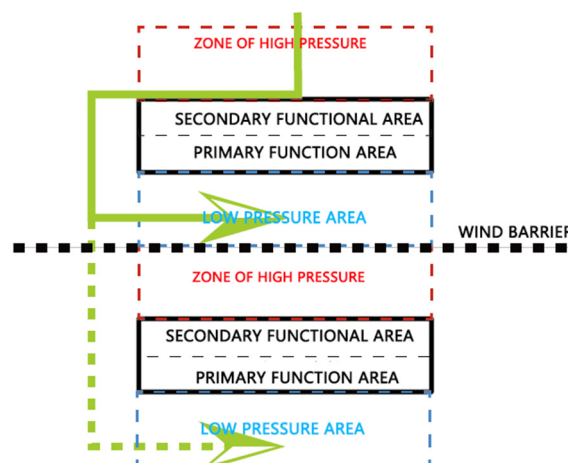


Figure 11. Architectural planning and layout

2. General layout of the head goose type

Dream Lake waterfront community (Figure 6) for the control of virus transmission provides a more reasonable spatial layout mode, that is, parallel to the wind direction of the building group in the center of the axial position of the arrangement of a building, which will be referred to as the "head of the wild goose building". Due to the existence of the "Head Goose Building", the Head Goose Building in front of the building surrounded by a semi-enclosed courtyard has become a high-pressure area, a natural barrier blocking the three buildings to send wind to each other, there is only a high-pressure area of the wind into the building of the situation. At the same time, the back of the Head Goose Building parallel wind direction of the inner formation of low-pressure area, the outer formation of high-pressure area, so the back of the building mutual air supply is not common, the main ventilation for the building on both sides of the mutual air supply. If the "head goose building" is set as a non-residential building of the office building category, then such a "head goose type general layout" can become a very idealized form of building layout to cope with the spread of virus blocking.

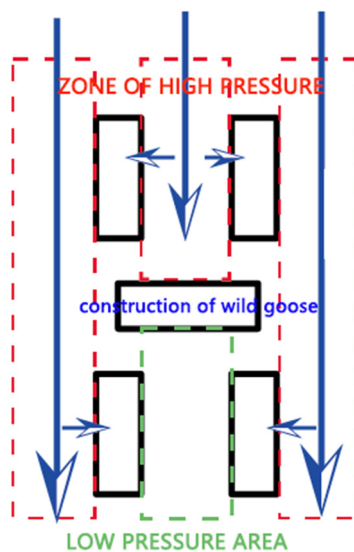


Figure 12. Dream Lake waterfront community spatial layout mode

3. Reduction of building density

The wind environment is affected by the building density, and the high capacity and high density of the settlement environment also adversely affects the ventilation of the settlement. Observations of building ventilation outside residential communities of different densities show that as building density increases, the number of single building blocks increases, and the obstruction of wind by buildings intensifies, making it difficult for wind to enter the interior of settlements. High-density housing reduces the comfort of natural ventilation outside the building, and is also not conducive to the spread of viruses. Therefore, for the layout of residential buildings, to reduce its building density, to ensure the comfort of the building wind environment, reduce the risk of virus transmission [10]. Therefore, the author suggests that the building spacing in line with the "urban residential planning and design code" GB50180 on the basis of appropriate consideration to further reduce the density of the building in order to obtain a better impediment to the spread of the virus effect.

4. The use of computer simulation of building wind environment

The system proposes that it is appropriate to use computers to simulate the wind environment of the site under typical climatic conditions. Therefore, before construction and renovation, designers can analyze the relevant building groups through computer simulation to optimize the layout of the building groups.

4. Conclusion

When design is combined with health needs, cities can become supporters of people's healthy lives. The article's research on building ventilation layout to reduce the risk of respiratory infectious disease transmission not only focuses on technical optimization, but also incorporates thinking about the climate space system. By combining Swire's building ventilation software analysis with climate adaptation concepts, a series of optimization strategies are proposed, such as two-way window openings, head-geese master plan layouts, and reduced building density, which provide a feasible path to a healthier city. This is not only a reflection on the Wuhan community, but also an exploration of the future of urban construction, contributing to the creation of a more comfortable and healthier urban life.

Acknowledgments

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