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Abstract	Since urban development began, Beijing courtyard homes have struggled with issues like population growth, renewal and renovation, and a lack of available housing. While the population is growing, the size of the original house remains intact for the occupants. In light of this incremental growth, the primary methods of remodeling the main house involve advancing the exterior wall, making use of the front porch to expand the living space, and adding a loft at height of approximately 6–7 m on the hard roof of the room, with stairs or climbing ladders connecting the upper and lower levels. However, despite the fact that ventilation is crucial to the home's indoor environmental condition, the designers did not give it enough consideration before the restoration. The goal of this essay is to investigate the effects—both good and bad—of two variations on the quadrangle's front porch and loft designs on the patterns of indoor ventilation. The comparative analysis approach is employed as the primary method in the study, with the front porch and loft serving as two variables to examine the internal ventilation of four distinct building models using computational fluid dynamics (CFD) techniques. The sectional airflow study and the 1.5 m height cloud in plane results show that the loft isolates the indoor airflow organization to some extent and makes the high interior windows less effective. Although the effect of occupying the front porch on ventilation is not significant, other effects on aspects other than ventilation need further study.

Keywords (separated by '-')	Beijing courtyard - CFD - Indoor environment - Ventilation analysis

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The Effect of the Front Porch and Loft on Natural Ventilation of the Main House in Beijing Courtyard

10

Zhongzhong Zeng and Zichen Liang

Abstract

Since urban development began, Beijing courtyard homes have struggled with issues like population growth, renewal and renovation, and a lack of available housing. While the population is growing, the size of the original house remains intact for the occupants. In light of this incremental growth, the primary methods of remodeling the main house involve advancing the exterior wall, making use of the front porch to expand the living space, and adding a loft at height of approximately 6–7 m on the hard roof of the room, with stairs or climbing ladders connecting the upper and lower levels. However, despite the fact that ventilation is crucial to the home's indoor environmental condition, the designers did not give it enough consideration before the restoration. The goal of this essay is to investigate the effects—both good and bad—of two variations on the quadrangle's front porch and loft designs on the patterns of indoor ventilation. The comparative analysis approach is employed as the primary method in the study, with the front porch and loft serving as two variables to examine the internal ventilation of four distinct building models using computational fluid dynamics (CFD) techniques. The sectional airflow study and the 1.5 m height cloud in plane results show that the loft isolates the indoor airflow organization to some extent and makes the high interior windows less effective. Although the effect of occupying the front porch on ventilation is not significant, other effects on aspects other than ventilation need further study.

Keywords

Beijing courtyard · CFD · Indoor environment · Ventilation analysis

10.1 Introduction

As the primary area of urban renewal in Beijing, the courtyards face issues including hazardous homes, subpar living conditions, and tensions between new and old structures, according to SDG 11 “sustainable cities and communities”, these issues need to be addressed urgently. The main house of the courtyard serves as the primary residence for its inhabitants, and in the context of incremental development, the rise in the population has resulted in a growing need to expand the main house's living space. This need can now be met by occupying the front porch and expanding the interior with a loft. The problem is

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A. Hasan et al. (eds.), *Design for Health*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-3-031-36316-0_10

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that the increasing demand for living space has led designers to overlook the effect of adding and modifying the main house on indoor and outdoor natural ventilation, and relevant studies have not paid enough attention to the natural ventilation of courtyard houses, so this paper explains how the two building configurations, the front porch and the loft, act on the indoor and outdoor natural ventilation of the main house through a comparative study.

10.2 Methods

This study uses a quantitative research method to build four architectural models of a courtyard with or without a front porch and with or without an additional loft, from which we can learn how the two variables above affect the indoor ventilation of a room, while also allowing designers and residents to better understand the indoor ventilation of a courtyard. This study's steps are as follows: (1) Arrange the architectural data and building measurements of the courtyard, and then use sketch up to create four distinct models. (2) Simplify and fix the models, as well as create the boundary conditions. (3) Open the ANSYS 2021 program, load the models, and configure the simulation's settings. The results acquired by ANSYS have been shown to be trustworthy in the developed theoretical framework and research methodology. (4) Compare and assess indoor airflow patterns, wind speed, and other factors, including any modifications brought on by various models.

10.2.1 Comparative Case Study Through Simulation

Beijing courtyard has been extensively studied and mapped as a representative example of traditional residential structures. Although there are many other buildings techniques and main house forms in use today, the modeling in this study is based on the most typical main house sizes and shapes. The main house has inside windows that are 1.16 m above the ground, a depth of 5.1 m, a width of 9.3 m, and a height of 6.3 m (Bingjian 1999).

The effect of roof shape, height, and ventilation methods on the indoor thermal environment performance of buildings were summarized as a result of a comparative study on the ventilation performance of multi-story roofs of traditional buildings in Myanmar carried out by CFD (Zune et al. 2020). The scholar Aydin made two comparative case studies on the effect of the "Cumba" structure of traditional Turkish houses on indoor ventilation, and proposed a plan typology to promote wind-driven indoor houses (Aydin and Mirzaei 2017). Therefore, this paper analyzes the influence of two classical structures of the main house on indoor ventilation by means of a simulated comparative case study method.

10.2.2 Simulation Methods

Adopting the same software and methods used in similar studies can ensure the authenticity of the results. CFD turbulence model can predict three-dimensional airflow and pressure distribution in indoor and built environment (Singh and Sharston 2021), in CFD research, 62% of scholars use ANSYS software, and 66% use RANS basic turbulence model (Toja-Silva et al. 2018). So the numerical simulation approach was selected using the same solution equations and techniques as in related research findings, and ANSYS series Fluent commercial software was employed. The second-order difference equation and the RNG k-ε in RANS turbulence model are used to calculate the diffusion term since it is necessary to take into account both inside and outdoor wind settings (Jing-yu et al. 2022). At 10 heights above the ground in Beijing, the boundary conditions are chosen as the predominant wind direction and the average wind speed with 5.5 m/s. The building facade is non-slip in the model, and the entering and exiting flows are represented by the conditions "violet-inlet" and "pressure-outlet", respectively (Wei et al. 2022).The calculation area is shown in Fig. 10.1. The boundary conditions of

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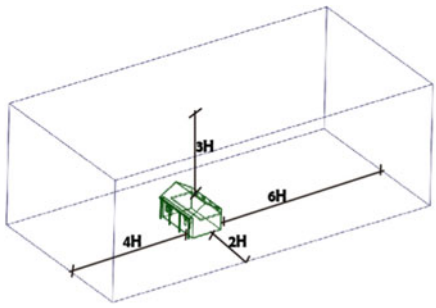

Fig. 10.1 Calculation area schematic

the indoor natural ventilation simulation refer to the average wind velocity of the window openings in the main room obtained by CFD simulation in the case of case 1 building with a front porch, with 1.8 m/s at the window inlet and 1.8 m/s at the back wall window as the outlet.

10.2.3 Simulated Cases

The case 1 is main house was separated into two examples of outside wind environment simulation with and without a front porch after the research to build a typical model, as illustrated in Fig. 10.2. The case 2 by adding a 3.4 m high floor slab, the interior was separated into two examples of indoor wind environment simulation with and without a loft, and the model developed by disregarding the extraneous features is illustrated in Fig. 10.3.

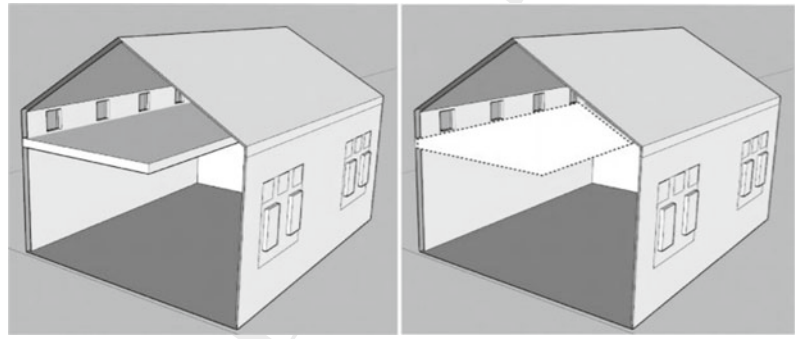

Fig. 10.2 Comparison of two models of the main house outdoor

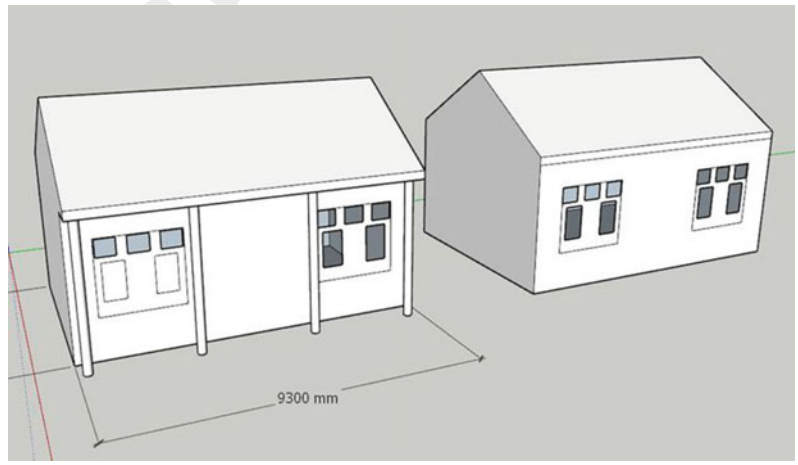

Fig. 10.3 Comparison of two models of the main house indoor

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10.3 Results

10.3.1 Effect of the Front Porch

Figure 10.4 depicts a model of the main house with a front porch on the left and a model of the inhabited main house's front porch on the right. The region of the static wind zone with wind speed less than 0.5 m/s is bigger near the front porch than in the other instance, with an average wind speed of 1.9 m/s and 0.9 m/s in the case without a front porch. The reason for this is because the airflow beneath the roof is sluggish and the pressure is high, causing the airflow to ascend quickly and cause more vortex and disturbance on the leeward side of the roof.

10.3.2 Effect of the Loft

Figure 10.5 depicts the inside ventilation effect, with the wind speed cloud and airflow traces superimposed. The airflow enters from the window and travels upward in the room without the loft construction, resulting in greater indoor ventilation throughout the space. The room has a bigger vortex at the ground level in the case of the loft structure, which results to a loss in local ventilation effectiveness, mostly because the floor slab blocks the updraft and diminishes the ventilation impact of the windows on the rear wall of the main house.

10.4 Discussion

As the primary residence of the courtyard's residents, it is important to examine the natural ventilation of the main house. The presence of the main house's architectural front porch is necessary, and the loft structure has an impact on the original ventilation path of the interior, it can be deduced from the outdoor examination of the wind environment. According to certain studies, traditional residential research offers a distinctive viewpoint that can be used to combine socially-based solutions to economic and environmental issues (Lezcano and Burgos 2021). For this study, the small size of the quadrangle rooms becomes less in living space as the population increases means that residents face the dual challenges of living environment and economic pressure. Then the significance of the study on natural ventilation is to provide the residents of Beijing courtyard with the positive or negative impact of the renovation addition on the existing wind environment in an incremental context, which will later be continuously supplemented and improved in synergy with different disciplines. What is insufficient is that the effect of more morphological types of houses of Beijing courtyards on natural ventilation should be further discussed in the follow-up study.

10.5 Conclusion

The original architectural design in the courtyard building should not be modified as much as possible; only the inappropriate sections or structures need to be replaced, according to the numerical simulation study of indoor and outdoor natural ventilation of the main house building. In order to provide warmth and wind shelter in the winter, the building's front porch might weaken incoming airflow. In the summer, however, the porch can encourage local ventilation by raising the average wind speed in the area, which will improve internal ventilation.

In actuality, the loft serves as a living space, but due to poor loft ventilation, the building may need to use air-conditioning more frequently in the summer, which increases the energy use of the building. In order to accurately simulate ventilation in a courtyard, more complicated factors like the nearby structures, the surrounding vegetation, and the envelope structure must be taken into account. The role of the front porch of the building is not only reflected in indoor ventilation, the front porch is a kind of building indoor–outdoor transition space, which has the role of shading, rain, rest, and so on. In short, in the analysis of natural ventilation should focus on interdisciplinary, multiangle and multilevel research problems in the subsequent research.

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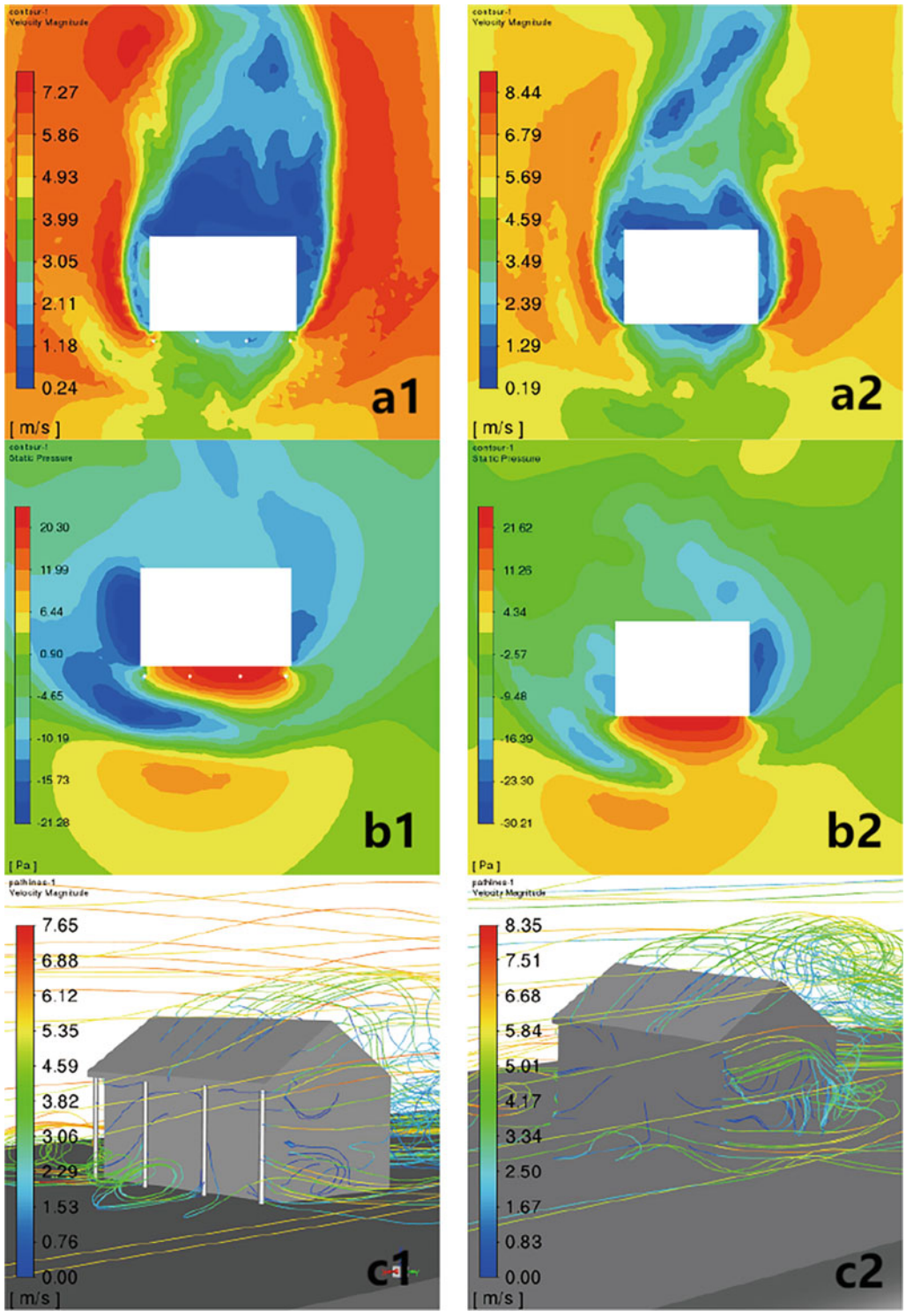

Fig. 10.4 Comparison of outdoor wind environment simulation results (the left picture is the model of the main house with front porch, the right picture is the model of the main house without front porch)

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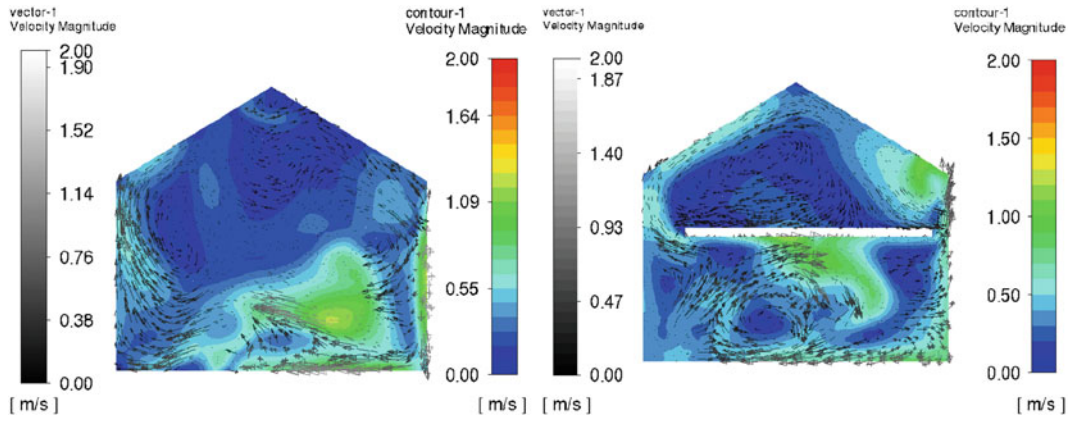

Fig. 10.5 Indoor ventilation analysis diagram (left diagram without loft ventilation, right diagram with loft ventilation)

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