Numerical study the influence of balcony in college dormitory on indoor environment in winter: A case study in Jinan, China

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ABSTRACT

The ventilation rate of dormitory in winter affects the living quality and learning state of students, while the balcony will affect the indoor ventilation of dormitory. In order to explore the influence of different locations, floor heights and building types on the ventilation rate and indoor environment of the dormitory in winter, this paper used the computational fluid dynamics software PHOENCIS and the multi-area network model software CONTAM coupling calculation method to simulate the indoor ventilation conditions of the dormitory in a university with or without balconies under three building types. The results show that the average ventilation volume with balcony is 44.04 m^3/h lower than that without balcony. When there are balconies, the room ventilation rate of the first floor of ordinary rectangular building, the second floor of L-type building and the first floor of rectangular-ambulatory-plane building are the largest. The room ventilation rate of different positions on the same floor of ordinary rectangular building is the lowest. Considering comprehensively, it is better to choose rectangular-ambulatory-plane dormitory buildings when there is a balcony.

INTRODUCTION

At present, many college dormitories adopt natural ventilation. Due to the low temperature in winter, dormitory staff choose to open fewer windows or not to open windows in order to reduce heat dissipation, which seriously affects the air circulation in the dormitory, making the ventilation volume and environmental conditions of the dormitory fail to reach the expected goal Lei et al. (2017). Low ventilation in dormitory has significant influence on the transmission of respiratory diseases Li et al. (2019). Using natural ventilation can greatly improve the indoor environment of winter dormitory Sun et al. (2011). The balcony will affect the indoor and outdoor airflow profile and indoor air velocity, thus changing the indoor thermal comfort.

Dormitories in colleges and universities are relatively densely populated dwellings, so the slight change of ventilation rate is more likely to affect the study and life of indoor personnel. Izadyar et al. (2020b)showed that the influence of balcony depth on average indoor air quality significantly depends on the orientation of the building. Han et al. (2015)combined CFD wind environment simulation, CONTAM multi-area airflow simulation and EnergyPlus energy consumption simulation software to compare the accuracy of different air infiltration rate calculation methods for building energy simulation, and pointed out that in energy simulation, CFD multi area coupling method should be selected to estimate the permeability, so as to consider the complexity of building structure, weather profile, surrounding terrain and shielding effect. Herring et al. (2016)combined the CONTAM multi-area building simulation tool with the outdoor dispersion model to evaluate how the fidelity of wind pressure input and the complexity of indoor model affect the predicted ventilation rate of the study building. It can be seen that many studies adopt the method of combining CONTAM with other software.

Although predecessors have done a lot of research, there is currently a lack of large-scale research data on the influence of balconies on indoor ventilation, and it is difficult to support reasonable improvement of balconies Izadyar et al. (2020a). There are fewer studies on the influence of university dormitory balconies on indoor ventilation and environment, and such buildings deserve more attention because of their high population density. Accurate wind pressure coefficients are required when CONTAM is applied to air flow simulation, and PHOENICS can provide these parameters. Therefore, through the combination of PHOENICS simulation and CONTAM ventilation simulation, this paper focuses on exploring the influence of dormitory balcony, dormitory location, dormitory building type and other factors on indoor ventilation. This study takes university dormitory as the entry point and enriches the research results of building balcony.

METHODS

Numerical study strategy

Accurate meteorological parameters and wind pressure coefficient files are needed when the software CONTAM is used for ventilation simulation. Using PHOENICS to simulate the outdoor wind environment, the wind pressure on the building surface can be obtained and the wind pressure coefficient file can be provided for CONTAM. The simulated coupling strategy is shown in Figure 1.

First, a full-scale model of PHOENICS dormitory building was established to simulate the outdoor wind environment, and the wind pressure coefficients of different rooms under different building types were obtained. Secondly, the air pressure coefficient was input into CONTAM as a necessary parameter, and the result of ventilation volume of the dormitory was simulated by combining with other parameter settings. The results of ventilation volume were analysed, and the influence of balcony on dormitory ventilation was obtained. The type of dormitory with balcony studied is shown in Figure 2.The balcony studied in this paper is a glass enclosed balcony with openable windows to enhance dormitory ventilation.

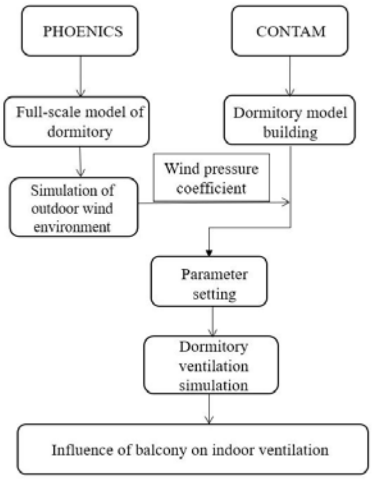
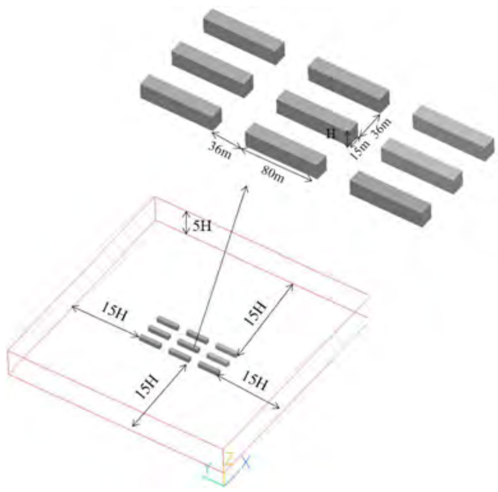


Figure 1. Simulation coupling strategy

Figure 2. Side view of a dormitory with balcony

PHOENICS simulation

The wind environment around the dormitory building was simulated by PHOENICS, and then the wind pressure on the building surface was obtained. Each full-scale model contains 9 buildings, with the middle one as the research object. The height of the building is 18 m, and the boundary distance of the building is 15H. Considering that different dormitory building types were affected by different outdoor wind environment, three full-scale dormitory models of different building types were established, which were ordinary rectangular, L-type and rectangular-ambulatory-plane respectively. The geometric models



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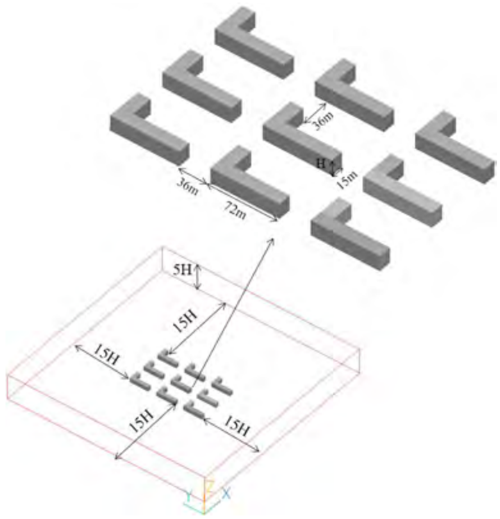

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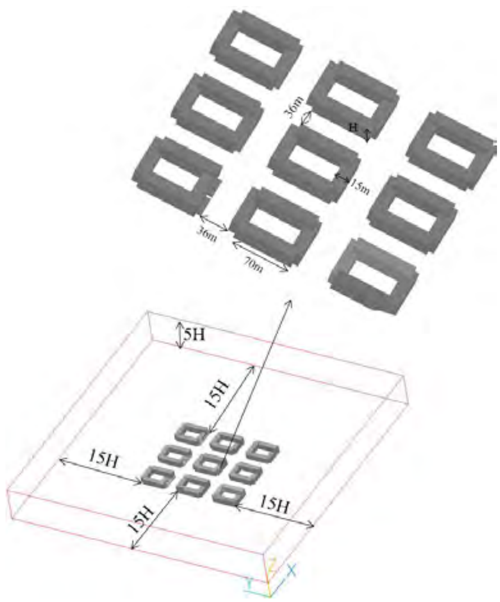

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Figure 3. Schematics of buildings' layout: (a) rectangular configuration, (b) L-shape configuration, (c) rectangular-ambulatory-plane configuration

of the three types of dormitory buildings are shown in Figure 3.

In the outdoor wind environment simulation, the air flow is turbulent flow, and the RNG k-ε model is applied. The k-ε two equations are expressed by Equations (1) and (2).

$$\frac{\partial(\rho k)}{\partial x}+\frac{\partial(\rho k\mu_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left(a_k\mu_{eff}\frac{\partial k}{\partial x_j}\right)+G_k+\rho\varepsilon \quad (1)$$

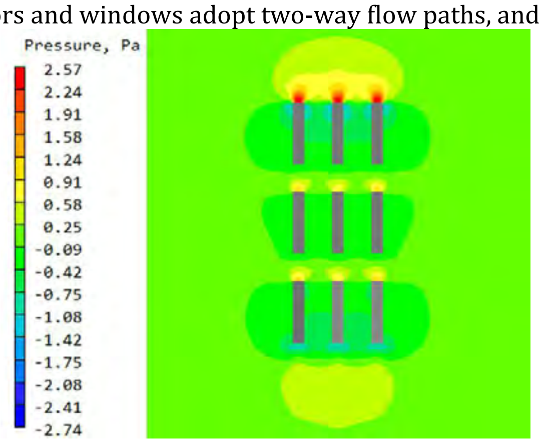
$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon\mu_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left(a_k\mu_{\text{eff}}\frac{\partial\varepsilon}{\partial x_j}\right)+\frac{C_{1\varepsilon}^{'}\varepsilon}{k}G_k+C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \quad (2)$$

where k is turbulent kinetic energy, $C_{1\varepsilon}$ and $C_{2\varepsilon}$ are empirical constants of 1.42 and 1.68 respectively, μ_{eff} is the diffusion coefficient. The full-scale wind environment simulation results of the dormitory (taking the wind direction of 90° as an example) are shown in Figure 4.

Jinan is the representative of the typical cold climate zone in Chinese. The monthly average temperature in January is about -3.0 °C. The dominant wind direction in Jinan in winter is east. The average wind velocity in Jinan in winter is 2.9 m/s MHURD (2012). The velocity variation of a typical design day ranges from 2.0m/s to 4.0m/s. In order to consider the influence of different flow directions on the wind pressure on the building surface, the wind environment around the building and the wind pressure on the building surface were obtained when the flow directions were 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315° respectively. Taking L-type building as an example, the wind pressure coefficient of the room on the south side of the third floor is shown in Figure 5.

CONTAM simulation

The same dormitory building model in CONTAM was divided into two types: with balcony and without balcony. The overall dimensions of the dormitory are 6.0m in length, 3.2m in width and 3m in height, and the balcony area is 4.8m^2. The dormitory building model is shown in Figure 6(a) (taking the ordinary rectangle building as an example). The airflow channel of the room with balcony is the door, inner window and outer window, and the airflow channel of the room without balcony is the door and window. Doors and windows adopt two-way flow paths, and



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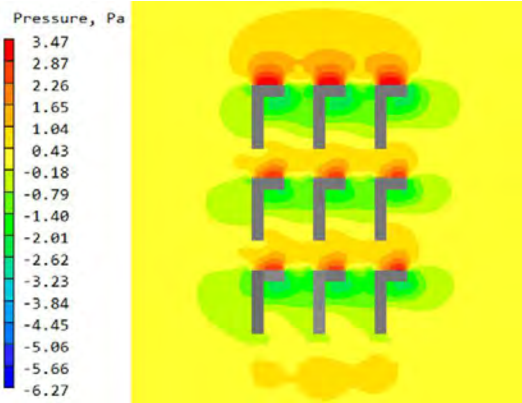

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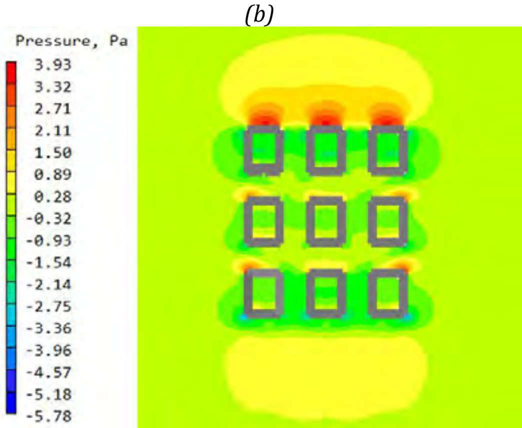

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Figure 4. Simulation results of full-scale wind environment of dormitory building (taking the wind direction of 90° as an example): (a) ordinary rectangular building, (b) L-type building, (c) rectangular-ambulatory-plane building

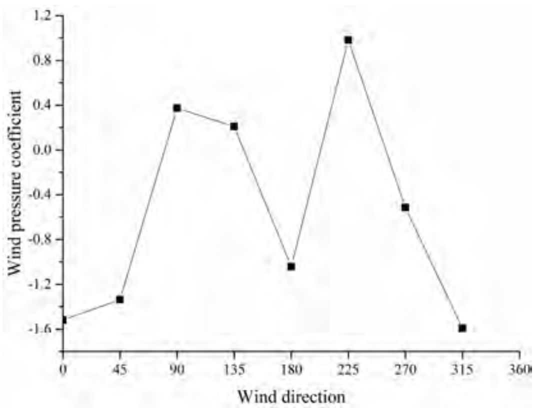


Figure 5. Wind pressure coefficient of the room on the south side of the third floor (taking L-type building as an example)

staircases are designed with one-way orifice paths. In this study, the model was simplified and the room was divided into areas such as southeast, northwest and so on. The specific division is shown in Figure 6(b) (taking the ordinary rectangle building as an example).

The room temperature was set at 20 °C. The wind speed was set according to the weather file. The wind direction was E which was the most in winter MHURD (2012). In the two-way flow path, the flow index was 0.78, and the width of the external window was 0.08m. The wind pressure coefficient used in the study was calculated by Equation (3) after the external surface pressure of the building was obtained by PHOENICS simulation.

$$C_P = \frac{2\Delta P}{\rho u_0^2} \tag{3}$$

where ΔP is the wind pressure difference on the exterior surface of the building, C_p is the wind pressure coefficient, u_0 is the wind speed at the reference height [m/s].

Evaluation criteria

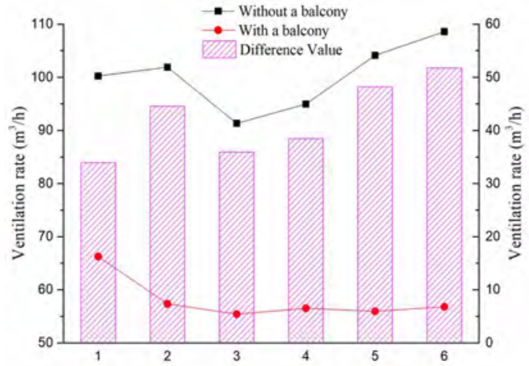
The evaluation criteria of the research results are as follows: the dormitory personnel density is less than 0.4 persons/m^2, the minimum fresh air volume is 26 m^3/h MHURD (2012), the dormitory is naturally ventilated, the fresh air volume is equal to the ventilated volume, and the default is four-bed room, and the ventilation rate should not be less than 104 m^3/h.

RESULTS

Ventilation rate of different floors with or without balcony

A room on the north side and a room on the south side of the three building types were selected for comparison. The ventilation rate of the two rooms with and without balconies was analysed respectively, and the difference value of the ventilation rate of the rooms with and without balconies was calculated. When the building type is ordinary rectangular, the comparison of ventilation rate of rooms on different floors with and without balconies is shown in Figure 7.

As can be seen from the figure, the ventilation rate of the room on the north side and the room on the south side has a similar trend with the change of floors. When there is no balcony, the ventilation rate of the south and north rooms on the third floor is the minimum, which are 91.04 m^3/h and 91.32 m^3/h respectively. When there is no balcony, the ventilation rate of the fifth and sixth floors basically meets the standard requirements of 104 m^3/h. When there is a balcony, the ventilation rate of the rooms on the south and north sides is the largest on the first floor, which is 67.38 m^3/h and 66.26 m^3/h respectively, while the ventilation rate of the rooms on the second and sixth floors fluctuates slightly, around 55 m^3/h. When there is a balcony, the ventilation rate of each layer does not meet the requirements. The ventilation rate difference between floor three and floor six with and without balcony increases successively.



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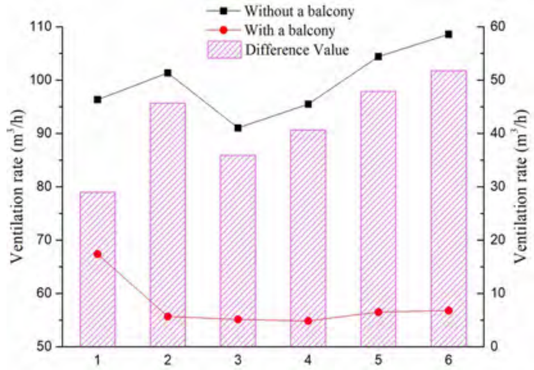

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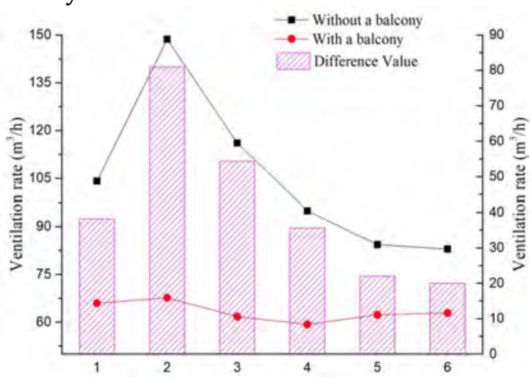
Figure 7. Comparison of ventilation rate of rooms on different floors in rectangular dormitories with or without balconies: (a) north, (b) south

When the building type is L-type, the comparison of ventilation rate of rooms on different floors with and without balconies is shown in Figure 8. Different from ordinary rectangular buildings, L-type buildings with or without balconies have the maximum ventilation rate of rooms on the second floor, which are respectively 168.44 m^3/h and 148.68 m^3/h on the south and north sides. When there is no balcony, the ventilation rate of floor 2-6 gradually decreases, and only the ventilation rate of floor 2 and floor 3 meets the requirements. When there are balconies, the change trend of ventilation in different rooms on the north and south sides is different, which may be affected by the architectural form.



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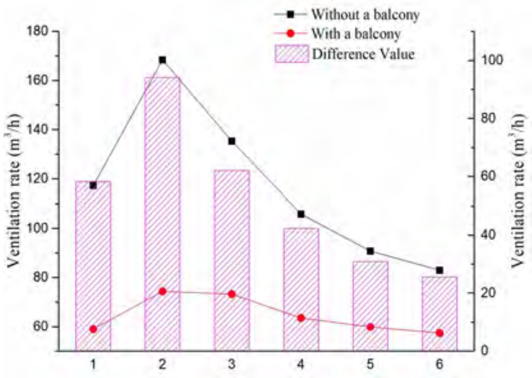

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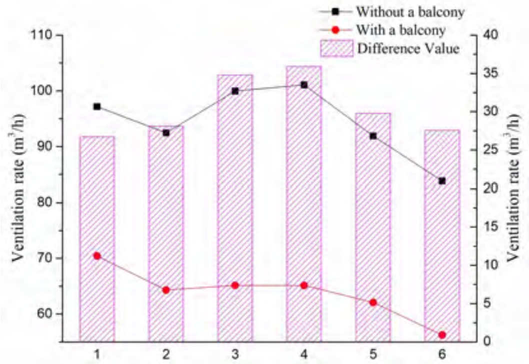
Figure 8. Comparison of ventilation of different floors in L-type dormitories with or without balconies: (a) north, (b) south

When the building type is rectangular-ambulatory-plane, the comparison of ventilation rate of rooms on different floors with or without balconies is shown in Figure 9. As can be seen from the figure, the changes of ventilation volume of the rooms on the south and north sides are no longer similar, and the changes of ventilation rate of the rooms on the south side are greater. When there is no balcony in the room on the north side, the ventilation rate on the fourth floor is the maximum, which is 101.07m^3/h. When there is no balcony in the room on the south side, the ventilation rate on the fifth floor is the maximum, which is 111.93m^3/h. When there is no balcony, the ventilation rate of the rooms on the north side cannot meet the requirements, while only the rooms on the fifth floor on the south side can meet the requirements.



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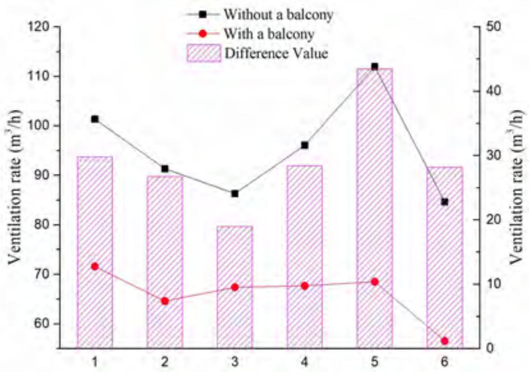

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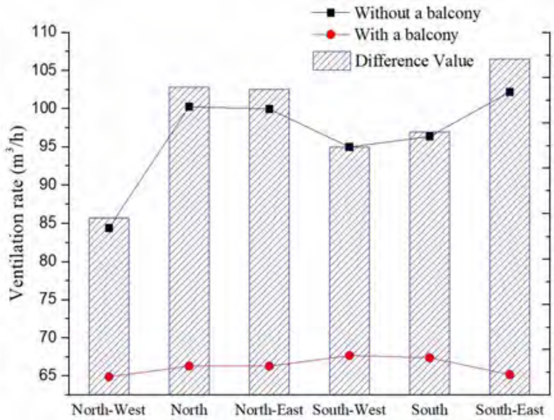
Figure 9. Comparison of ventilation rate of rooms on different floors in rectangular-ambulatory-plane dormitories with or without balconies: (a) north, (b) south

Ventilation rate of different rooms on the same floor

Depending on the prevailing wind direction and the layout of the building, the amount of air ventilated in different locations on the same floor varies. This paper explores the ventilation rate of rooms on the 1st, 3rd and 5th floors in different building types. When the building type is ordinary rectangular, the comparison of ventilation rate of dormitories at different positions on the same floor with or without balconies is shown in Figure 10. As can be seen from the figure, when there is no balcony, the ventilation rate of the room on the first floor changes greatly, and the room on the northwest side is the smallest, which is 84.36m^3/h. The room on the southeast side is the largest, which is 102.18m^3/h, which does not meet the requirements. When there is no balcony, the change of the fifth floor is the least, and the ventilation rate of the rooms in all directions is maintained at about 104 m^3/h, which basically meets the requirements. When there is a balcony, the ventilation rate of the rooms on the first floor and the fifth floor has a small change, about 66 m^3/h and 56 m^3/h respectively. The ventilation rate of the third floor rooms does not meet the requirements when there is no balcony.



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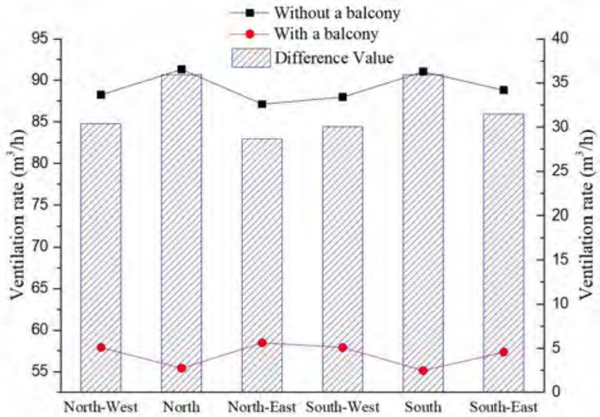

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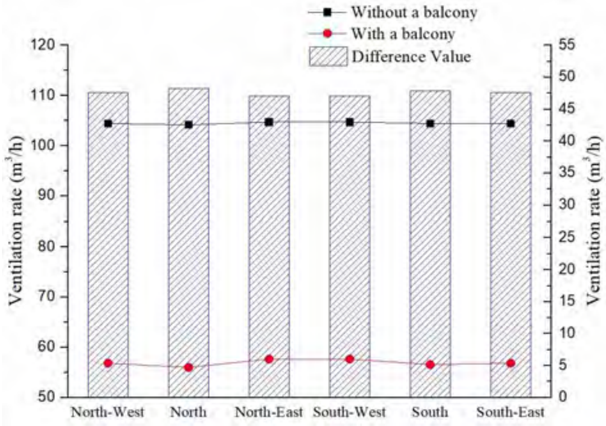

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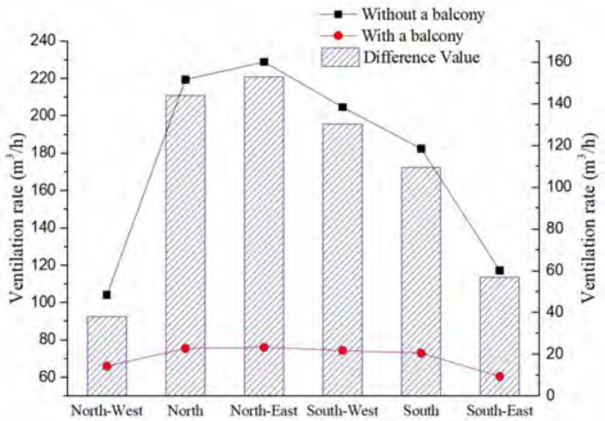
Figure 10. Comparison of ventilation rate of different positions on the same floor with or without balconies in ordinary rectangular dormitory buildings: (a) floor 1, (b) floor 3, (c) floor 5

When the building type is L-type, the comparison of ventilation rate of dormitories at different positions on the same floor with or without balconies is shown in Figure 11. The variation range of ventilation rate of rooms in different positions on the same floor with and without balconies is higher than that of ordinary rectangular rooms.



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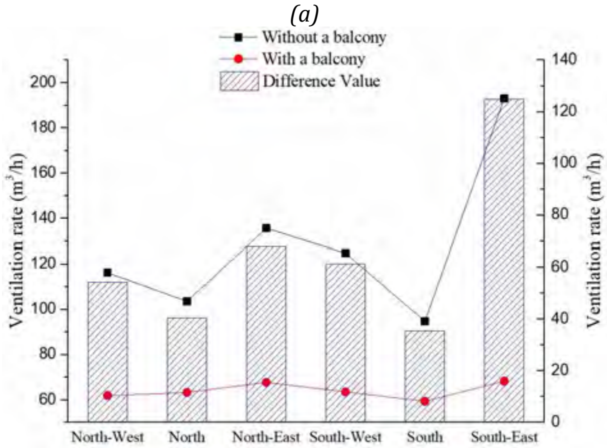

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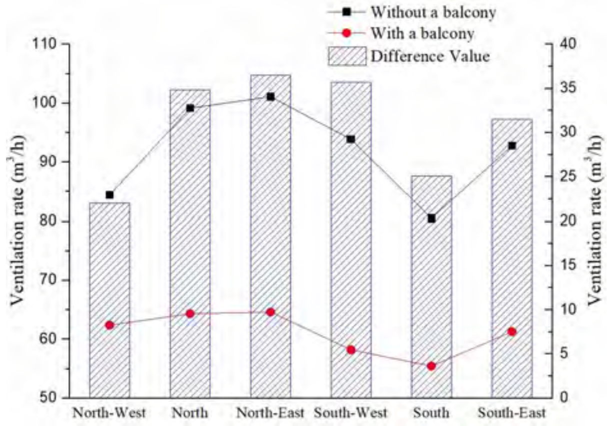

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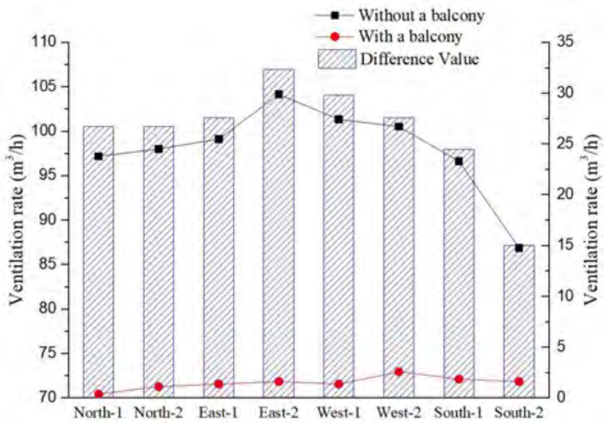
Figure 11. Comparison of ventilation rate of different positions on the same floor with or without balconies in L-type dormitory buildings: (a) floor 1, (b) floor 3, (c) floor 5

When there is a balcony, the ventilation rate is 5 m^3/h higher than that of ordinary rectangular buildings. When there is no balcony, the minimum ventilation rate of rooms at different positions on the first floor is 104.12 m^3/h, which all meet the requirements. When there is no balcony, the ventilation rate of the north and south rooms on the third floor is less than 104 m^3/h, and the ventilation rate of the other rooms meets the requirements. When there is no balcony, the ventilation rate of each room on the fifth floor does not meet the requirements.



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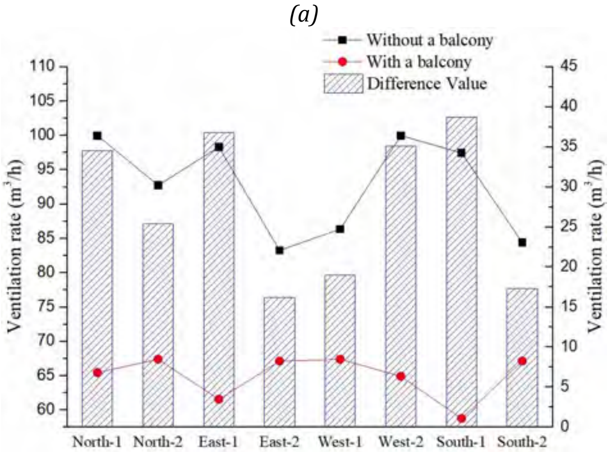

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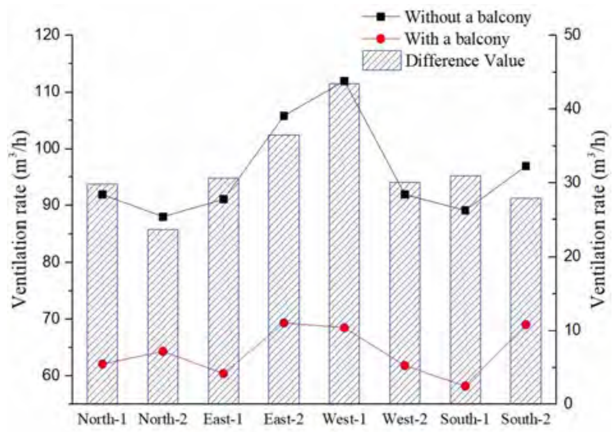

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Figure 12. Comparison of ventilation rate of different positions on the same floor with or without balconies in rectangular-ambulatory-plane dormitory buildings: (a) floor 1, (b) floor 3, (c) floor 5

When the building type is rectangular-ambulatory-plane, the comparison of ventilation rate of dormitories at different positions on the same floor with or without balconies is shown in Figure 12. When there is no balcony, the room on the east side of the first floor has the largest ventilation rate, which is 104.13 m^3/h; the room on the south side of the fifth floor has the largest ventilation rate, which is 111.93 m^3/h; the ventilation rate of other rooms does not meet the requirements. When there is a balcony, the ventilation rate of the rooms on the third and fifth floors varies more than the first two types.

Comparison of ventilation volume of three building types

This section analyses the ventilation of all rooms with or without balconies. The comparison of ventilation rate of the three building types without balconies is shown in Figure 13. It can be seen from the figure that the ventilation rate of the dormitories in the rectangular-ambulatory-plane building is relatively small on the whole, and the ventilation rate of a few rooms meets the requirements of the code. The fluctuation of ventilation rate of ordinary rectangular building dormitories is small, and its mean value basically meets the requirements. The ventilation rate of L-type building dormitory is larger as a whole, but the ventilation rate of different rooms varies greatly. The comparison of ventilation rate of the three building types with balconies is shown in Figure 14. Ordinary rectangular building dormitory ventilation rate is the least. The average ventilation rate of L-type buildings is similar to that of rectangular-ambulatory-plane buildings, and the ventilation rate of different rooms in rectangular-ambulatory-plane buildings has little fluctuation.

DISCUSSION

The balcony of dormitory building has obvious obstruction to the air flow. The ventilation rate of ordinary rectangular, L-type and rectangular-ambulatory-plane dormitory buildings with balcony is 36.57 m^3/h, 66.71 m^3/h and 20.04 m^3/h lower than that without balcony, with an average of 44.04 m^3/h. The balcony of rectangular-ambulatory-plane building has little effect on the ventilation. When there are balconies, the difference of ventilation between different floors of ordinary rectangular dormitory building is small, which may be caused by different building structures. Longer corridors and more corners may be part of the reason.

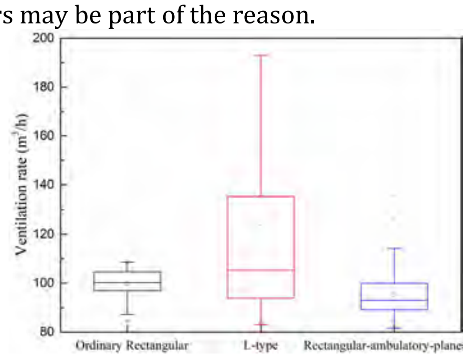

Figure 13. Comparison of ventilation rate of three building types without balconies

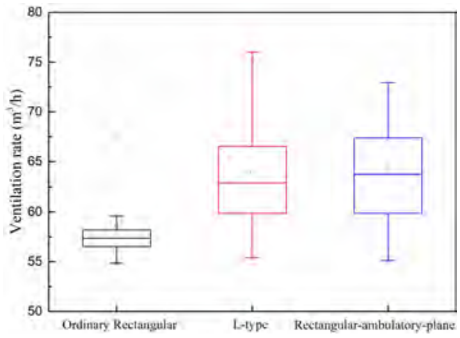

Figure 14. Comparison of ventilation rate of three building types with balconies

By comparing the ventilation of different rooms on the same floor, it is found that the ventilation of three types of dormitory buildings with balcony is the largest on the first floor. This may be due to the influence of the density of the building model, and the dense buildings change the wind environment around the research object. In the future research, we can change the space between buildings, so as to get the influence of different building density on the wind environment around the middle building.

With balcony, when the window opening of all rooms in three building types is 0.08 m, the ventilation rate cannot reach 104 m^3/h, which may be related to the window opening. Increasing the window width will solve this problem, but it will also reduce the temperature in the dormitory. In this case, increasing the window width is not easy to achieve. Although the existence of balcony reduces the ventilation, it prevents the cold air from entering the room directly. Therefore, exploring the balance of the influence of balcony on indoor temperature and ventilation is the focus of the next research.

Through the above data, it is found that the average ventilation of L-type dormitory is the largest when there is no balcony, and the average ventilation of rectangular-ambulatory-plane buildings with balcony is the largest. Therefore, when building high-density dormitory buildings in colleges and universities, we can choose the two kinds of buildings correspondingly, and avoid the use of ordinary rectangular buildings. In the design, other forms of buildings that conform to the prevailing wind can be considered, or the passageway for guiding wind can be added in the building.

CONCLUSIONS

Using the method of combining PHOENCIS and CONTAM, this paper focuses on analysing the influence of balcony, different floors and different locations of the same floor on the indoor ventilation of college dormitory. The following conclusions were drawn:

(1) The balcony of the dormitory has a significant obstruction effect on the air flow in the dormitory, and the average ventilation volume with the balcony is 44.04 m^3/h lower than that without the balcony.

(2) When the width of the outer window is 0.08 m, the ventilation rate of the three types of dormitories with balconies cannot meet the minimum fresh air volume standard.

(3) In the construction of high-density dormitory buildings in colleges and universities, the buildings without balconies can be designed as L-type, and the buildings with balconies can be designed as rectangular-ambulatory-plane.

CONFLICTS OF INTEREST

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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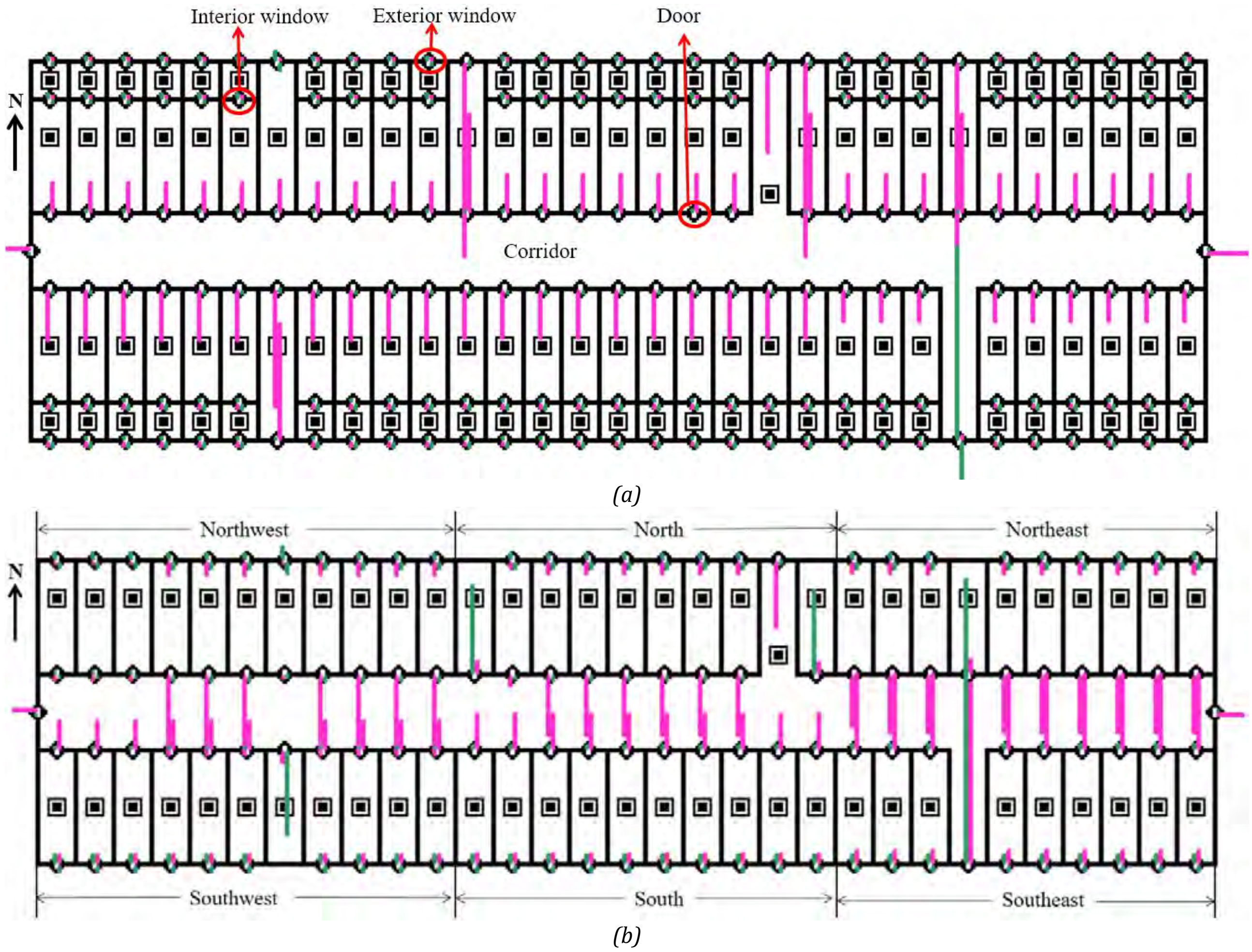

Figure 6. CONTAM model of ordinary rectangular dormitory building: (a) with a balcony, (b) without a balcony