Numerical simulation the effect of natural ventilation on Indoor Environment Quality in the inner-corridor-type student dormitory in winter

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Abstract: Poor air quality in the dormitory will affect students’ physical and mental health and reduce their learning efficiency. The environmental status of university dormitory is gaining more and more attention. The indoor environment quality is always affected by outdoor condition during the heating period due to the requirement of natural ventilation. Using ANSYS Fluent software establishes a full-scale indoor and outdoor inner-corridor-type dormitory taking into account the different floor numbers. The results revealed that the living area on the south side of the corridor has a higher temperature and carbon dioxide concentration compared with the north side of the corridor. The balcony and corridor play an important role in maintaining the temperature of the dormitory. The mean velocity on the first floor is the lowest, and there is no significant difference in the air velocity in the living area on both sides of the corridor. The living area on the fifth floor has the better ventilation effectiveness. The results of this study will help architects understand the impact of natural ventilation on the indoor environment in inner-corridor-type dormitory.

1. Introduction
The inner-corridor-type student dormitory is characterized by simple structure and low cost, but has been widely applied in north China and most of the student dormitories in universities do not have air-conditioning system or mechanical ventilation. The students spend most of their time in the dormitory beside the classroom especially in winter.

Literature review found that the indoor environment quality induced by natural ventilation has been increasingly paid attention [1-3]. For instance, Wu et al. [4] investigated the thermal environment of university dormitory in China in cold climate and provided an adaptive thermal behavior function that can be used to analyze indoor thermal comfort. Sun et al. [5] conducted a series of measurements in the campus building and concluded that lower air change rate was associated with a slightly increment of general and skin sick building syndrome symptoms. Lei et al. [6] analyzed the effect of natural ventilation on the students’ sleep quality and indoor thermal comfort, and obtained the optimal window opening area in students’ dormitories.

However, there are few studies using natural ventilation to improve the indoor environment quality of inner-corridor-type student dormitory in winter. Therefore, the present study explored the effect of natural ventilation on the indoor environment in a typical inner-corridor-type student dormitory in northern China using the computational fluid dynamic (CFD) method. The analyses on the three proposed cases were conducted including different floor numbers. The target parameters, indoor airflow velocity, temperature and CO₂ concentration, were mainly studied. The study found that the balcony helps to maintain a certain range of temperature in living area within the dormitory. There is a significant
difference in air temperature and CO₂ concentration in the living area on both sides of the corridor, while no significant difference in the air velocity when the window opening area is the same.

2. Research method

2.1. Introduction of dormitory building

Building two is a typical inner-corridor-type student dormitory building that was chosen for the CFD simulation. Building two has 6 floors, the window is north-south orientation, and the vertical height is 18m. Building two is located in the central area of the student dormitory unit. Building one and three have the same shapes as the Building two, which are located in southern and northern of Building two, as shown in Figure 1. Since the width of the dormitory in the east-west direction is much longer than the length in the north-south direction and vertical height, therefore, periodic zone for a typical student room is selected to pursue the impact of natural ventilation on indoor environment. In addition, the 1st, 3rd, and 5th floors are separately built in this study.

![Figure 1. Dormitory building layout (m), (a) Side view, (b) Top view](image1)

2.2. Computational model

Three dormitory buildings are selected in the computational domain. However, the buildings of Building two and Building one are not included to draw the mesh as shown in Figure 2. The computational domain of this study followed the recommendation of the Architectural Institute of Japan (AIJ) guidelines [7]. The lateral and the top boundary is set as 5H length away from the building in which H is the vertical height of the building. The outflow boundary is set to 15H length behind the building.

![Figure 2. Isometric viewing of computational model](image2)

Figure 3 shows the computational model in side view and top view. The three dimensional size of a student room is 8 m × 4.36 m × 3 m (long × width × height). The thickness of the exterior wall and interior wall between the balcony and the living area are 0.37 m and 0.24 m, respectively. The width of the corridor is 2 m. The exterior window located at 1.2 m height with a size of 2.4 m × 1.0 m (width × height). The heating radiator is applied in winter with a size of 0.5 m × 0.1 m × 0.96 m. Heat source with a size of 0.5 m × 0.5 m × 0.5 m is considered at the height of 1.0 m. The ventilation opening size in exterior and interior windows is set to 0.15 m × 1 m. Due to the infiltration effect of the door, the gap that penetrates the air around the wooden door is converted into a small opening at the bottom of the door. The opening size is set to 0.04 m × 0.5 m (width × height). The interiors of the dorms on both
sides of the corridor are identical. Three cases were simulated in this study including different floor numbers as presented in Table 1. Due to the significant computational resource required for all three floors, this study separately considered the first, third and fifth floor in the CFD simulation.

| Case number | Floor number | Dimension of opening (m × m) | Opening area(m²) |
|-------------|--------------|-----------------------------|------------------|
| Case 1      | First floor  | 0.15 × 1                    | 0.15             |
| Case 2      | Third floor  | 0.15 × 1                    | 0.15             |
| Case 3      | Fifth floor  | 0.15 × 1                    | 0.15             |

### 2.3. Grid distribution
ICEM CFD program is used to create the building geometry and draw the mesh with structural mesh. The grid number will exceed 7.0 million if all three floors are considered after testing, therefore, the model and corresponding mesh for first, third and fifth floors are drawn separately. Grid independence test is conducted including 2.92 million (coarse), 3.5 million (medium), and 4.2 million (fine).

Table 2 presents the grid independence test. The results indicated that the medium grid generated much similar results compared with the fine grid. Therefore, the grid with grid number of 3.5 million was finally applied in this study. The minimum grid spacing near the wall was 0.01m, which was enough to capture a laminar sub-layer. The non-uniform grid used in the computations has a stretching ratio of 1.2 to 1.4 in all directions as shown in Figure 4.

| Grid number (-) | Coarse | Medium | Fine | ΔCM* | ΔMF* |
|-----------------|--------|--------|------|------|------|
| Average corridor temperature (K) | 264.4 | 296.13 | 306.49 | 12 | 3.5 |
| Average air velocity (m/s) | 0.0454 | 0.0486 | 0.05 | 7 | 2.8 |

*Δij=((ni-nj)/ni)×100%

### 2.4. Numerical modeling and boundary condition
CFD simulations were performed using the commercial CFD software package ANSYS Fluent 16.4. For incompressible flows, this paper uses a pressure-based solver. The pressure-velocity coupling adopts the SIMPLE algorithm. The pressure term difference method adopts the second-order format. The momentum term, the turbulent kinetic energy term, and the turbulent dissipation term, energy terms are calculated using a first-order format.

The inlet boundary condition is set to the velocity inlet, the turbulent intensity is specified as 5% and the turbulent length scale is 1.0 m. The inlet air temperature is set to 267.65 K. Five surfaces in a hexahedron heat source are set as the heat generating area except the top surface that is assumed as emission surface for exhaling the carbon dioxide. Heat of heat generating surface is defined as 250W designed according to the total heat source size of four adult men, computers and lamps [8]. A carbon dioxide emission rate of 2×10⁻⁸ m³/s and a temperature of 307 K are predefined [9]. The both sides surfaces of the computational domain are set to periodic boundary conditions [10].
3. Results and discussion

3.1. Airflow distribution around the building

Due to the effect of urban layout, the air velocity in urban areas is seriously degraded, and the reduction of air velocity will have a complex impact on natural ventilation. The flow pattern in the urban area depends on the layout of the building, especially the aspect ratio ($AR=H/W$), which is defined as the ratio of the average height $H$ of the building to the width $W$ of the street). When $AR\geq 1$, the wake of the upstream building will affect the downstream buildings, and the canyon wind will form [16].

![Figure 5. Mean streamlines velocity in the vertical plane ($z=2.5m$)](image)

It can be seen from Figure 5 that the airflow vortex is formed between the two buildings, and the flow velocity will decrease from 3.5 m/s to less than 1 m/s. The air velocity inside the dormitory is affected by the building layout.

3.2 Effect of balcony on the indoor air distribution in living area

![Figure 6. The air temperature and air velocity in the horizontal plane ($y=7.6m$), (a) Air temperature, (b) Air velocity](image)

The mean air velocity and mean air temperature in the horizontal plane at a height of 1.6 m from the ground are studied as shown in Figure 6. Figures 6(a) shows there is a significant difference between the outdoor temperature and the balcony temperature. The temperature has a large jump from the balcony to the living area. The mean air temperature of the dormitory in northern living area is higher than that in south living area. The air temperature in the living area is maintained at a high level due to the presence of the balcony. In other words, the balcony temperature is positively correlated with the indoor living area temperature. Figures 6(b) shows that mean air velocity of living area is higher than that in balconies and corridors. The air velocity of the balcony is close to the air velocity of the corridor, the indoor air flow is driven by buoyancy, the outdoor air flow is driven by the wind pressure, and the air velocity near the wall is reduced. The balcony is a buffer zone to avoid direct contact between the hot air in the room and the cold air outside. The corridor also played a similar role to the balcony, where the mean air velocity is...
low, resulting in less heat exchange in the living areas on both sides of the corridor.

**Table 3.** Mean air temperature (K) in different zones

| Case  | Balcony(N) | Living area(N) | Corridor | Living area(S) | Balcony(S) |
|-------|------------|----------------|----------|----------------|------------|
| Case 1| 276.92     | 287.55         | 292.13   | 293.93         | 282.6      |
| Case 2| 279.07     | 294.04         | 296.20   | 298.42         | 285.33     |
| Case 3| 278.77     | 291.96         | 293.86   | 296.53         | 284.45     |

The comparisons of mean air temperature and air velocity of each zone from Case 1 to 3 are shown in Table 3 and Table 4, respectively. Table 4 shows that the average temperature of the living area on the south side of the corridor is 5.1 K higher than the average temperature of the living area on the north side of the corridor. The average temperature of the balcony on the south side of the corridor is 5.9 K higher than the north side of the corridor. The temperature of the corridor is approximately close to the average of the temperature of the living area on both sides of the corridor. The average temperature difference between the balcony and the living area on the south side of the corridor is 12.2 K, and the average temperature difference on the north side of the corridor is 12.9 K.

**Table 4.** Mean air velocity (m/s) in different zones

| Case  | Balcony(N) | Living area(N) | Corridor | Living area(S) | Balcony(S) |
|-------|------------|----------------|----------|----------------|------------|
| Case 1| 0.07       | 0.14           | 0.02     | 0.11           | 0.06       |
| Case 2| 0.08       | 0.28           | 0.04     | 0.29           | 0.06       |
| Case 3| 0.07       | 0.19           | 0.02     | 0.19           | 0.06       |

The following conclusions can be drawn from Table 4: The balcony air velocity does not change significantly with the number of floors changes. The air velocity of the balcony is the fastest, the air velocity of the corridor is second, and the air velocity of the living area is the lowest on every floor and the mean air velocity of the living area and balcony on both sides of the corridor is basically the same on every floor when the window opening area is the same.

### 3.3. Indoor environmental quality for different floor numbers in living area

**Figure 7.** The contour distribution of living area in the horizontal plane (y=1.6m, y=7.6m, y=13.6m),
(a) Air velocity, (b) CO2 concentration.
Figure 7(a) shows the air velocity contours in the horizontal plane. The indoor air velocity is kept below 0.4 m/s, and the mean velocity on the third floor is the highest. The mean velocity on the first floor is the lowest, and there is no significant difference in the air velocity in the living area on both sides of the corridor. Figure 7(b) shows the CO2 concentration in the dormitory on the north side of the corridor is significantly lower than the south side of the corridor. Ventilation effectiveness (VE) is used to evaluate the effect of natural ventilation efficiency as shown below:

\[ \varepsilon_{VE} = \frac{C_e - C_p}{C_d - C_p} \]  

where, \( C_e \) is the CO2 concentration at the opening of the window between the balcony and the living area, \( C_d \) is the CO2 concentration at the opening of the door, \( C_p \) is the CO2 concentration at the emission surface. The smaller the value of \( \varepsilon \), the higher the ventilation efficiency.

Table 5 indicates that the ventilation efficiency of the living area on the north side of the corridor is significantly higher than that on the south side of the corridor when the window opening area is the same. The ventilation effectiveness on the fifth floor is the best.

| Table 5. VE (-) in the living area |
|----------------------------------|
| Area                              | Case 1 (1st floor) | Case 2 (3rd floor) | Case 3 (5th floor) |
| Northern living area             | 8.16               | 4.74               | 8.28               |
| Southern living area             | 36.23              | 21.98              | 82.61              |

4. Conclusion
The wind magnitude between the dormitory buildings is significantly reduced due to the layout of buildings (H/W=1.0). In this study, the wind speed decreased from 3.5 m/s to less than 1 m/s, the wind speed dropped by more than 71%. The balcony is a buffer zone between indoor air and outdoor air, which is helpful for maintaining the air temperature in the living area. There is no significant difference in the air velocity in the living area on both sides of the corridor when the window opening area is the same. The average temperature and CO2 concentration of the living area on the south side of the corridor is higher than the north side of the corridor. The results of this study will help architects understand the impact of natural ventilation on the indoor environment of inner-corridor-type dormitory.

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