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A Comparative Study on the Organization of Independent Fresh Air Flow

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Abstract

Purpose: The changes of fertility policies have led to a gradual increase in the number of "child-rearing" families, and current residences are no longer able to meet the new demand of family child-rearing. **Research design, data and methodology:** As an important facility for improving indoor environments, fresh air systems are essential for maintaining the living environment required by residents in "child-rearing" oriented adaptive housing. **Results & Conclusions:** This paper investigates two main types of fresh air supply modes to analyze the mode suitable for "child-rearing" residential housing, including ceiling air supply and underfloor air supply, where in-site measurement and software simulation are applied.
Keywords : Fresh Air, Air Supply mode, Child-rearing Family

JEL Classification Code: H31, I12, I31

1. Introduction

Housing is one of the most fundamental requirements for human survival and development. Since 1998, when China entered the era of commercial housing, the scale of urban residential construction has shown an ascending trend. Due to the changes of fertility policies in recent years, family structures have evolved and gradually shifted from "two-generation, three-person" nuclear family to the "three-generation, multi-person" extended family [1]. The involvement of grandparents assisting with child-rearing has gained its popularity, and the facilities suitable for one-child families may no longer meet the demands of the current family structure [2]. Additionally, housing should not only meet individual's basic living needs but also adapt to the advancements in family structures [3].

In the post-pandemic era, as an important facility to improve indoor air quality and living comfort, residential fresh air systems are gradually becoming a standard configuration for high-quality residential buildings. Although the market size of fresh air systems has grown rapidly in recent years, the overall configuration rate is still relatively low. Also, the standards for various types of buildings are not yet systematic, among which there is less research on fresh air design for child-rearing families.

For families with newborns and children in developmental stages, fresh air is particularly important for the growth of them. Fresh air systems continuously provide fresh air indoors, ensuring the cleanliness of indoor air and reducing the risk of children suffering from respiratory diseases. In addition, fresh air systems replace the traditional method of opening windows for ventilation, which avoid the safety risks of property and personal safety that may arise when children are at home alone and windows are opened.

The HVAC industry has kept exploring new systems for adaptive housing that is capable to accommodate the diverse

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needs of all-age people [4]. Ceiling air supply and underfloor air supply are two common forms of fresh air transport mode while the performances of which on radiation residential building are under urge to investigate. With the aid of PHOENICS software, a simulation of room ventilation under the two air supply modes is conduct based on the assumption that the geometric shape of the residential space and the volume of fresh air remain constant. This simulation is then compared with the actual measurement results of a certain project to study the adaptive fresh air organization methods suitable for "child-rearing" families, which provides reference to the real engineering practice.

2. Simulation

The fresh air system can be sorted into ceiling air supply systems and underfloor air supply systems according to the mode of supply and exhaust. Based on the principles of Computational Fluid Dynamics (CFD), the PHOENICS software was used to simulate the ventilation effects of ceiling air supply and underfloor air supply systems in a residential room in Nanjing City, and quantitatively analyze the differences between ceiling and underfloor air supply [5].

2.1. Physical Model

2.1.1. Room Model Parameters

Ignoring the influence of other furniture except for the bed, a room model with dimensions of 3.72m×8.4m×3.15m is esta blished. By changing the form and position of the air outlets, the physical models of the room equipped with the two different fresh air supply systems are shown in the Fig. 1.

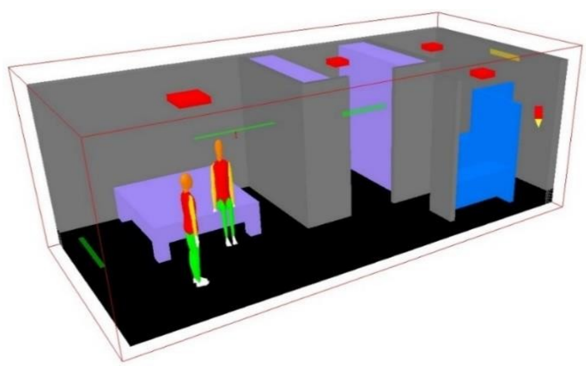


Figure 1. Physical model of the room

Both the ceiling air supply outlet and the underfloor air supply outlet are designed as slit tuyeres. The ceiling air supply outlet is located on the ceiling opposite to the bed, while the underfloor air supply outlet is located on the floor between the bed and the outer window; the return air outlet is located on the outer wall of the bathroom within the bedroom suite; additionally, an additional tuyere is set on the wall above the inner door of the bedroom.

2.1.2. Fresh Air Volume Parameters

According to the Jiangsu provincial local standard DB32/4066-2021 and DB32/4066-2021, the fresh air volume in this simulation is set at 70m3/h, and the additional air volume between the living room and the bedroom is set at 30m3/h.

2.2. Boundary Conditions

2.2.1. Wall Boundary Conditions

In this model, the floor radiation surface is set as a constant-temperature boundary, with the average surface temperature of the radiation panel set between 25-27℃ for comfort requirements (the upper limit is 29℃). The inner and outer walls are set as adiabatic boundaries.

2.2.2. Fluid Boundary Conditions

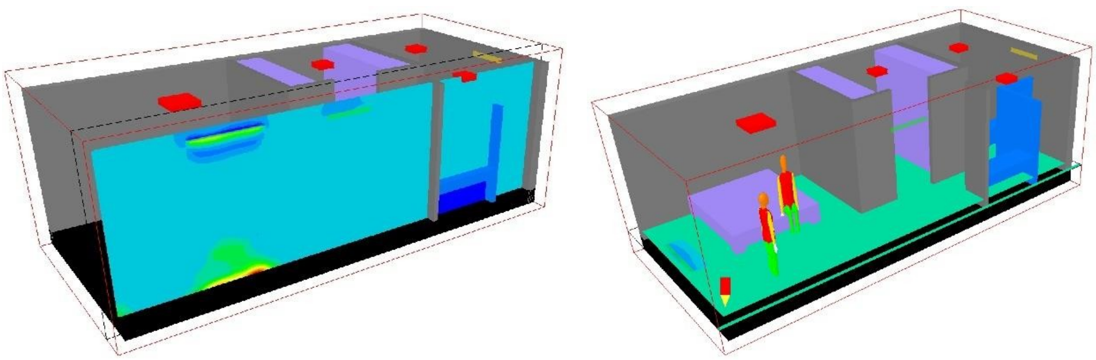
The underfloor air supply outlet is set as a velocity inlet boundary. It is assumed that the air velocity at the supply tuyere is uniform, with the velocity size set according to the average supply air velocity corresponding to the actual measured fresh air volume. The gaps of the doors are set as free pressure outlets, allowing air to flow freely under the influence of indoor and outdoor pressure differences.

2.3. Results and analysis

The fresh air temperature is 15°C and the volume is 70m3/h for both supply modes. The indoor pressure, velocity, and temperature distribution contour maps of the two air supply modes are compared below.

2.3.1. Pressure Distribution

Two typical sets are selected for illustration: the pressure contour map of the ceiling air supply at y=3.6m and for the unde rfloor air supply at z=0.5m are shown below.



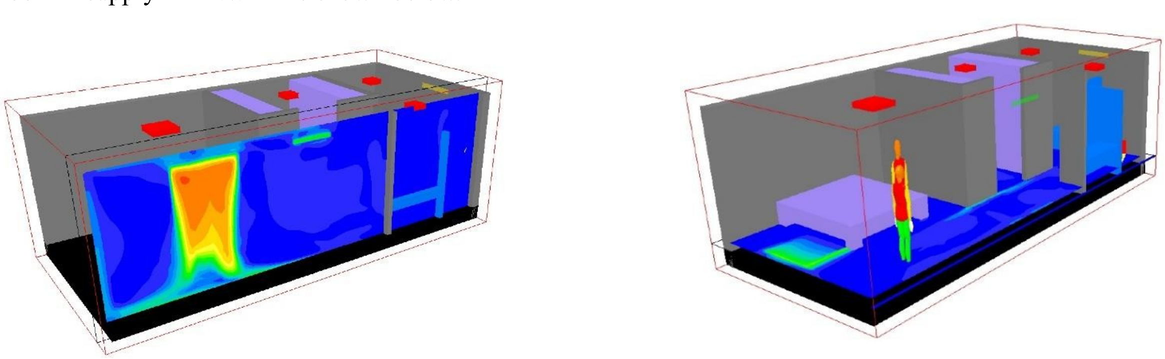
(a) Ceiling air supply. (b) Underfloor air supply.

Figure 2: Pressure distribution of fresh air outlet for two different models

Fig. 2. presents the pressure distribution contour maps on the two typical cross-sections. The figures show that the indoor pressure distribution of both fresh air supply modes is quite similar, which the pressure decreases as getting closer to the air supply tuyere, and the relative pressure of the room inner areas gets more uniform.

2.3.2. Velocity Distribution

Two typical sets are selected for illustration: the velocity contour maps of the ceiling air supply at y=3.6m and for the und refloor air supply at z=0.5m are shown below.



(a) Ceiling air supply. (b) Underfloor air supply.

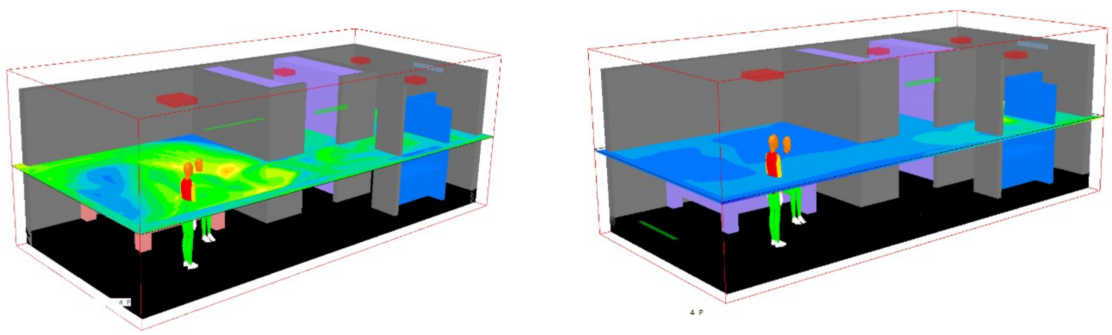
Figure 3: Velocity distribution of fresh air outlet for two different models

According to the Fig. 3(a) & (b) mentioned above, under the ceiling air supply mode, the air velocity is higher in the area close to the air outlet. As the fresh air enters the room and mixes fully with the indoor air, the momentum of the air gradually decreases. The air velocity in the main areas of the room is below 25m/s, with a slight draft sensation at human height, resulting in worse comfort. The carbon dioxide concentration is lower in areas of high air velocity and accumulates in areas of low air velocity.

Under the underfloor air supply mode, as shown in Fig. 3(b), the fresh air is introduced into the room at a velocity of 12m/s from the floor outlet, forming an upward airflow under the influence of the floor and the human heat source. The overall air velocity in the room is relatively low, with the velocity in the main areas inferior to 10m/s, which avoids creating a draft sensation and offers better comfort.

2.3.3. Temperature Distribution

Two typical sets are selected for illustration: the temperature contour maps at z=1.5m for both the ceiling and underfloor a ir supply modes are shown below.



(a) Ceiling air supply. (b)Underfloor air supply.

Figure 4: Temperature distribution of fresh air outlet for two different models

As shown in Fig. 4(a), under the ceiling fresh air supply mode, the vertical cross-sectional temperature distribution ranges from approximately 20°C to 25°C. The fresh air is initially at a lower temperature when it is sent out from the ceiling outlet, and gradually increases in temperature as it is mixed with the indoor air. Due to the influence of the lower surface temperature of the room's peripheral protective structure, the temperature near the outer wall is lower than that in the inner area of the room, resulting in horizontal temperature stratification.

From Fig. 4(b), it can be seen that the fresh air is sent out from the floor slot and spreads in all directions, rising upward due to the buoyancy of the warm air near the thermal radiation surface. As the fresh air is at a lower temperature, the area near the tuyere is cooler, while the room temperature is relatively higher further away from the tuyere. Except for the area close to the outlet, the overall temperature in the room is characterized by being higher at the bottom than at the top, and higher in the center than at the edges.

The contour maps reveals that the temperature distribution in the room differs little between the two modes. However, the underfloor air supply system produces thermal stratification in local areas compared to the ceiling air supply mode [6], a less draft sensation and greater comfort. From the perspective of child-rearing families, a lighter draft sensation and better replacement effect are more conducive to children's daily life and home study.

3. Measurement

3.1. Measurement Plan

Through PHOENICS simulation, it can be observed that the floor fresh air supply mode is slightly more effective in quality housing than the ceiling supply mode. A residence in Nanjing City that uses a radiant air conditioning independent fresh air system was selected for actual measurement, with the underfloor air supply mode adopted, and the underfloor air supply grilles

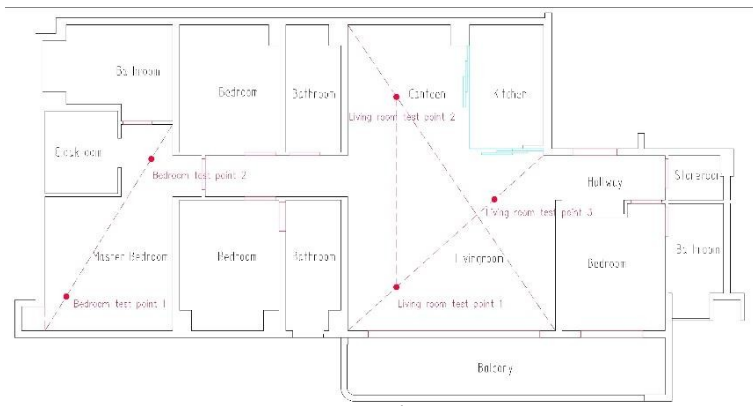
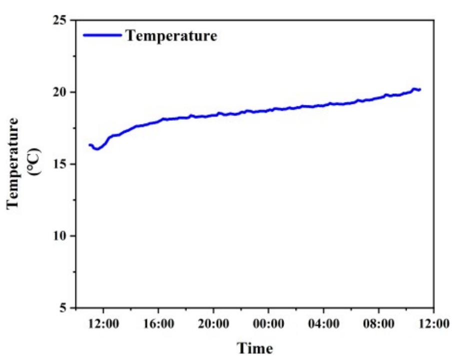


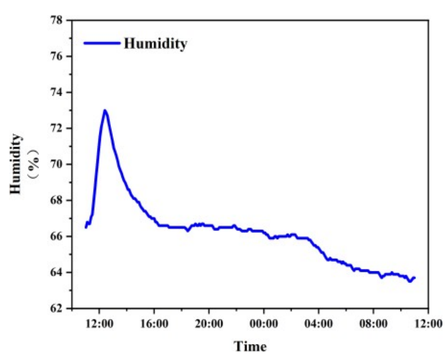
Figure 5: Diagram of test point layout

Before the experiment, the fresh air system was set to the highest speed, and the exhaust outlet was adjusted to ensure that the pressure difference between the indoor and outdoor could achieve a slight positive pressure of 5-100 Pa. The fresh air system was turned on. The temperature and humidity, carbon dioxide recorders were simultaneously activated, and the sound level meter and anemometer were started for data collection. Measurement was continuously conducted for 24 hours to purify the pollutants in the room. The fresh air system was then shut down, marking the end of the experiment.

3.2. Air Quality Measurement

The fresh air system was turned on at 11:00 AM and data was recorded continuously for 24 hours. The test results at five measurement points were plotted using Origin as is shown in Fig. 6-10 below.





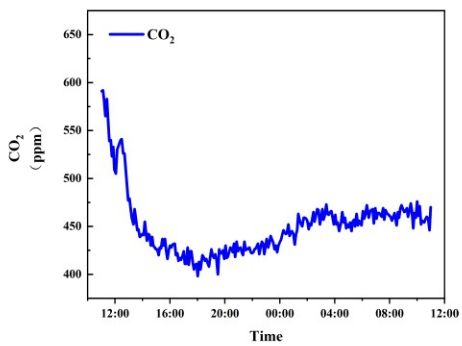


Figure 6: Test result curve of living room test point 1

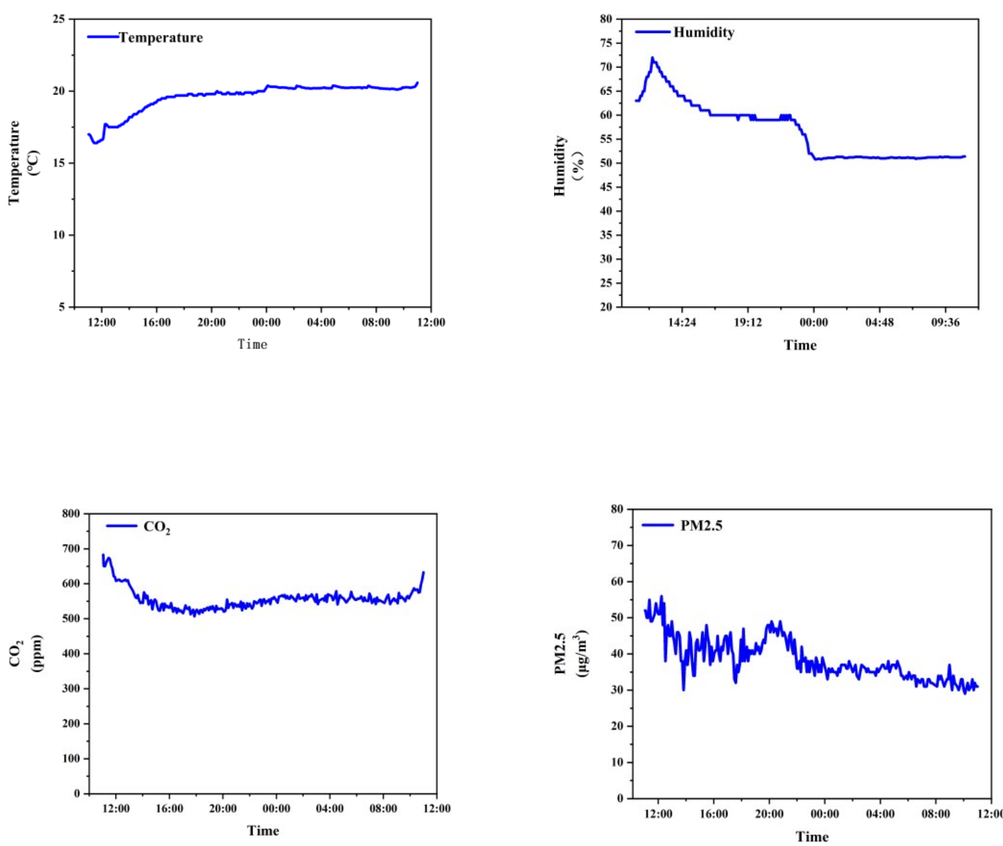


Figure 7: Test result curve of living room test point 2

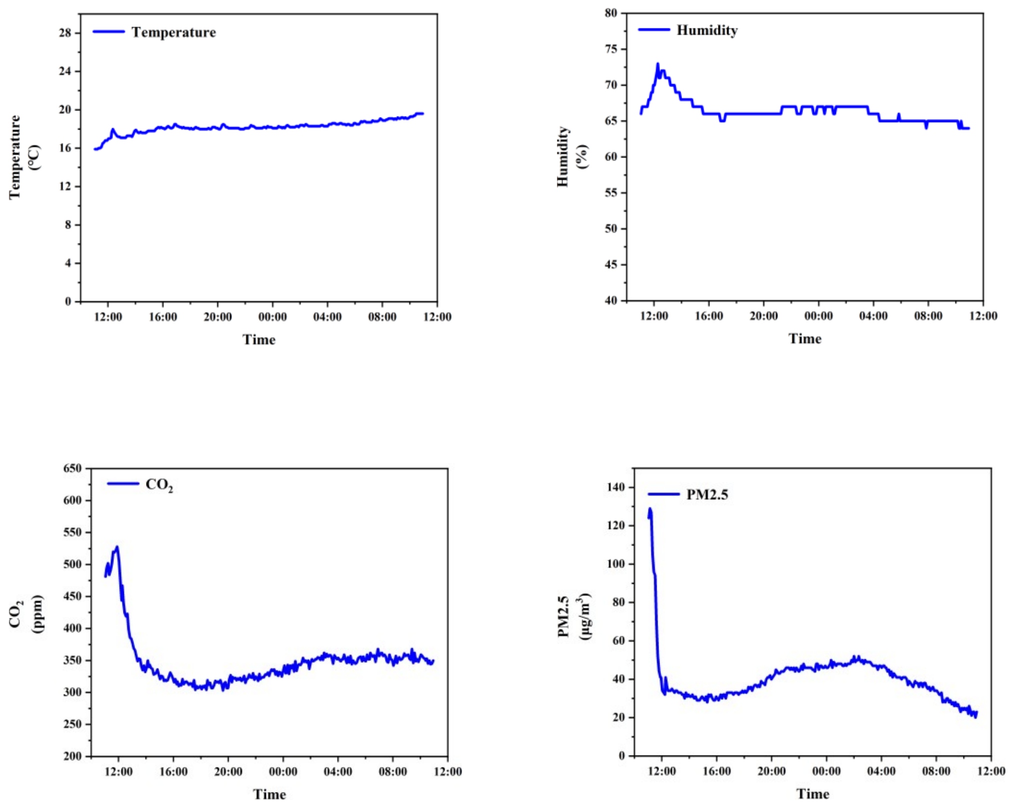
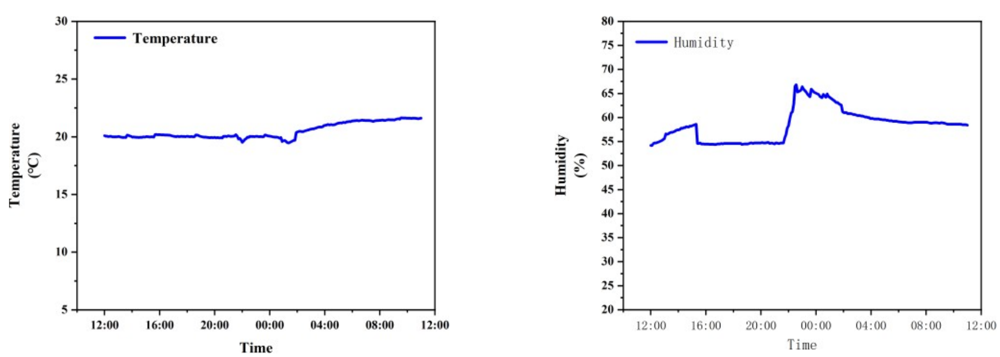


Figure 8: Test result curve of living room test point 3



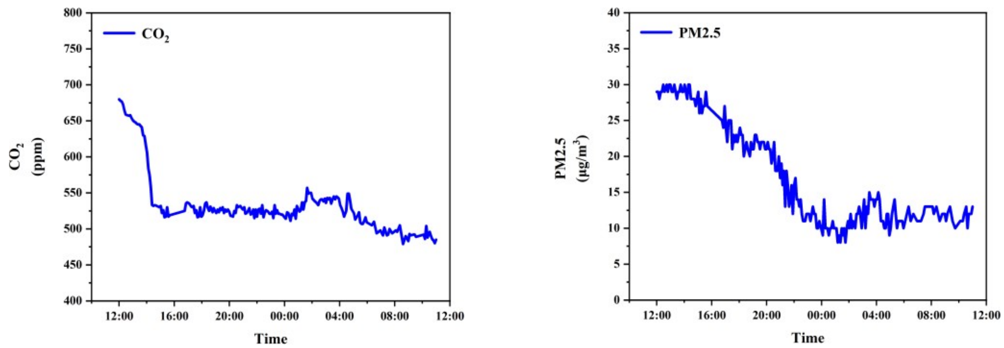


Figure 9: Test result curve of bedroom test point 1

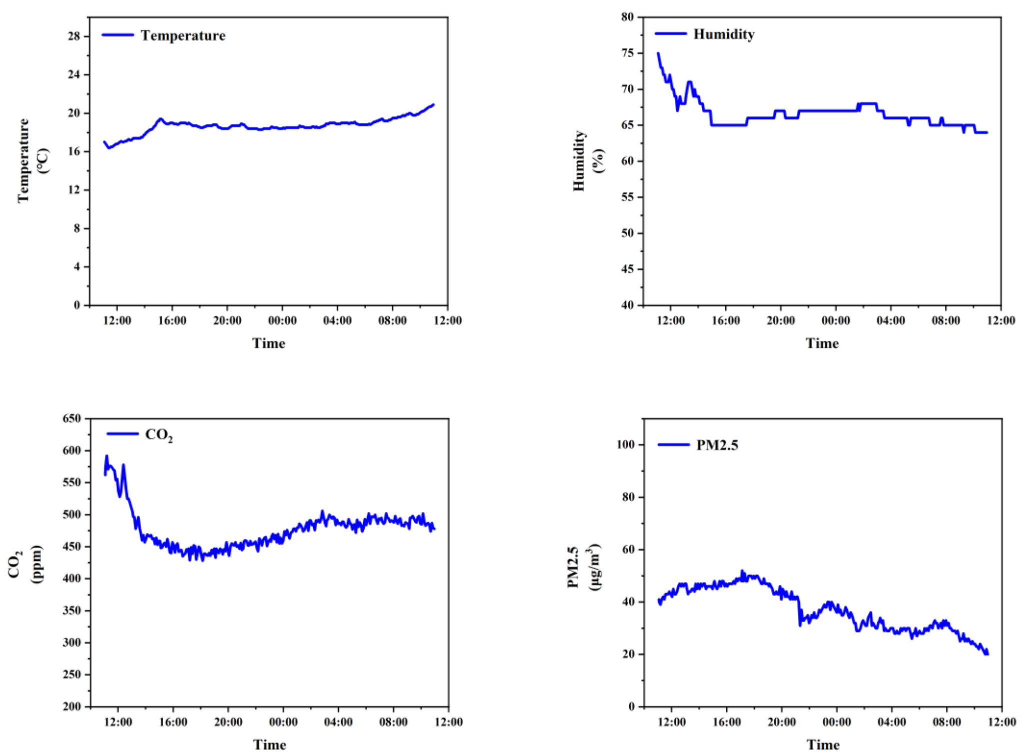


Figure 10: Test result curve of bedroom test point 2

After the analysis of variation curves of temperature, humidity, carbon dioxide concentration, and PM2.5, the following conclusions can be obtained:

1) Approximately 2 hours after the fresh air system is turned on, the indoor environment will meet the comfort requirements for both children and adults;
2) Under the influence of the fresh air system, temperature and humidity change relatively smoothly; whereas the concentration of carbon dioxide and PM2.5 are significantly affected by the fresh air, dropping rapidly within a certain period after being turned on, and then maintaining a stable state;

3) Since the doors and windows were tightly closed during the test, the humidity was not greatly affected by the choice of the test point. The temperature at the test point near the south-facing window remained stable after sunset, indicating the significant effect of the residence's fresh air system;
4) During the test, adjusting the fresh air valve flap stirred up dust from the fresh air outlet in the model room, causing a sudden increase in the PM2.5 curve at the living room test point 1 within the first hour of being turned on, which had little impact on the actual measurement results.

3.3. Measurement of Airflow Parameters

A hot-wire anemometer was used to test the fresh air supply tuyere, and the test results were plotted as a curve chart (black represents air temperature, green represents air velocity, red represents pressure, and blue represents air volume) in Fig. 11:

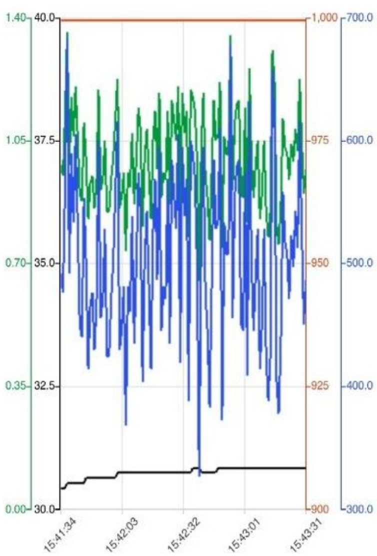


Figure 11(a). Result curve of tuyere of living room

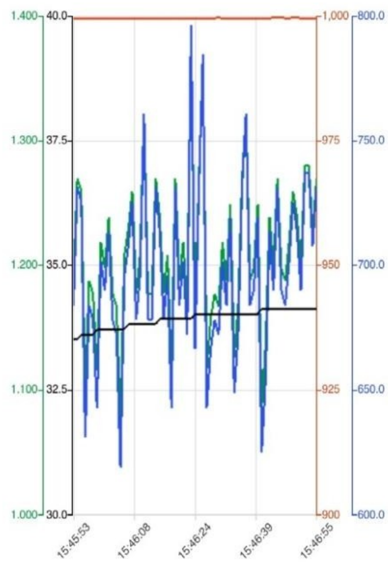


Figure 11(b). Result curve of tuyere of canteen

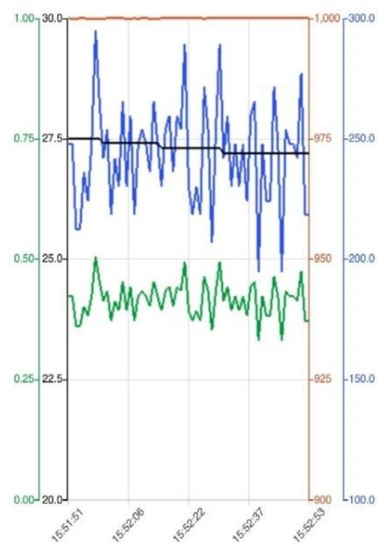


Figure 11(c). Result curve of tuyere of bedroom

Based on the variation curves of the airflow parameters, the air temperature and volume in the living room, dining room, and bedrooms are almost stable with marginal fluctuations. According to the electrical design of this residence, the master bedroom outlet is the least favorable end with the smallest air volume. The test results are in line with the electrical design.

3.4. Noise Measurement

A sound level meter was used to test the fresh air supply outlets, and the test results are as follows:

Table 1: Noise of living room fresh air outlet (A sound level).

Parameters	Tuyere of living room	Tuyere of canteen	Tuyere of bedroom
$L_{eq,T}$	21.1	26.5	14.6
SEL	31.1	36.5	24.6
L_{max}	24.1	27.4	17.8
L_{min}	19.3	25.6	12.1
L_5	22.5	27.1	16.7
L_{10}	22.1	26.9	15.7

L_{50}	20.9	26.5	14.4
L_{90}	20.1	26.1	13.1
L_{95}	19.9	25.9	12.8
SD	0.8	0.3	1.1

The results of noise test all comply with the evaluation criteria for indoor noise in residential buildings as stipulated in Article 7.1.1 of the Chinese standard GB 50368-2005. The permissible noise level in bedrooms and living rooms with closed windows does not exceed 50dB (A-weighted) during daytime, and does not exceed 40dB (A-weighted) at night.

4. Conclusions

This paper compares the indoor ventilation of underfloor air supply and ceiling air supply systems through simulation, and actually measures the trends of air quality, airflow, noise, and other parameters in a residence with the underfloor air supply system after the fresh air system is turned on during 24 hours. The analysis reveals that for child- rearing residential buildings, the sensitive perception of young children, as well as the needs for home study and entertainment, etc., the underfloor air supply system is more suitable. The various fresh air supply forms of adaptive housing should be determined by a combination of factors such as family structure and residential requirements.

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