ISSN 2706-655X Vol.6, Issue 1: 60-64, DOI: 10.25236/IJFET.2024.060110

Dynamic analysis of air quality and air flow control mode in residential buildings

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Abstract: *This study employs methods such as laboratory experiments, questionnaire surveys, and comparative data analysis to dynamically analyze the air quality in home environments. The research explores the impact of temperature regulation under different airflow control methods on the comfort of residents across different age groups. Through the investigation, we identify a stable and reliable airflow regulation method for effective control, achieving dynamic air quality standards in home environments to meet people's health requirements.*

Keywords: *Residential Buildings; Air Quality; Temperature; Airflow Control; Comfort*

1. Research Background

With the progress of society and the increasing demand for a high-quality life, indoor air quality has become a focal point of concern, especially against the backdrop of the COVID-19 pandemic, where the connection between air quality and physical health has become even more critical. This paper primarily explores the dynamic analysis of air quality in home environments and the study of airflow control methods.

According to statistical data, modern individuals spend approximately 80% to 90% of their time indoors. However, the introduction of metabolic waste from human activities and external pollutants leads to an increase in the types and concentrations of pollutants in indoor air, resulting in a significant decline in indoor air quality. The human body requires inhaling 10 to 13 cubic meters of air daily, and prolonged exposure to such environments can have adverse effects on both physical health and mental well-being. As early as 1983, the World Health Organization identified these issues as Sick Building Syndrome (SBS) after extensive investigations.

This paper focuses on two aspects of dynamic air quality analysis: firstly, the impact of air temperature on health. Air temperature influences the body's temperature regulation function. Elevated indoor temperatures may affect the body's temperature regulation, leading to symptoms such as increased body temperature, vasodilation, rapid pulse, and dizziness. Conversely, low temperatures may result in decreased metabolic function, slowed pulse and respiration, tightened skin, vasoconstriction, and decreased respiratory resistance. Generally, the most comfortable temperature range for the human body is 19 to 24 degrees Celsius. To enhance human comfort, it is necessary to control indoor temperatures appropriately, avoiding extremes. Additionally, further research is required to understand the variations in residential building temperature and their impact on residents' comfort.

Secondly, the study investigates the impact of traditional airflow control methods on air velocity. Wind speed significantly affects human comfort. Adequate wind speed promotes air circulation, aiding in heat dissipation and perspiration, thus maintaining bodily comfort. However, excessive wind speed may lead to excessive cooling of the body, causing discomfort and even potential health issues such as colds or respiratory diseases. Moreover, excessively fast wind speed may result in excessively dry indoor air, adversely affecting the skin and respiratory system. Generally, the most suitable wind speed for the human body in summer is around 0.3 m/s, and in winter, it is approximately 0.2 m/s. To enhance human comfort, it is essential to control air velocity appropriately, avoiding extremes.

Currently, there are three main types of indoor air improvement methods in mainstream residential environments: natural ventilation, fresh air systems, and small air conditioning systems or air purifiers in enclosed environments. While these methods improve certain aspects of air quality, each has its drawbacks.

This project primarily focuses on the dynamic analysis of air quality in home environments. It selects key indicators related to human health and employs a stable and reliable airflow regulation method for effective control, aiming to achieve dynamic air quality standards in home environments and meet people's health requirements.

2. Dynamic Analysis of Air Quality

To investigate the impact of temperature regulation under different airflow control methods on the variation of residents' comfort patterns in residential buildings, this experiment selected residents of a standard residential building as the research subjects. The floor plan of this residential building is shown in Figure 1. Thirty participants were randomly selected and divided into three age groups: 15-35 years old, 35-45 years old, and 45-60 years old.[1]

Under different environmental temperatures, we simulated participants' free activities in normal life. The data collected were analyzed using a combination of experimental measurements and questionnaire surveys.

Through this experiment, we found that airflow control methods significantly influence the impact of temperature regulation on residents' living comfort. Therefore, further exploration of the relationship between airflow control methods and temperature regulation is needed to provide more reference for improving residents' living comfort.

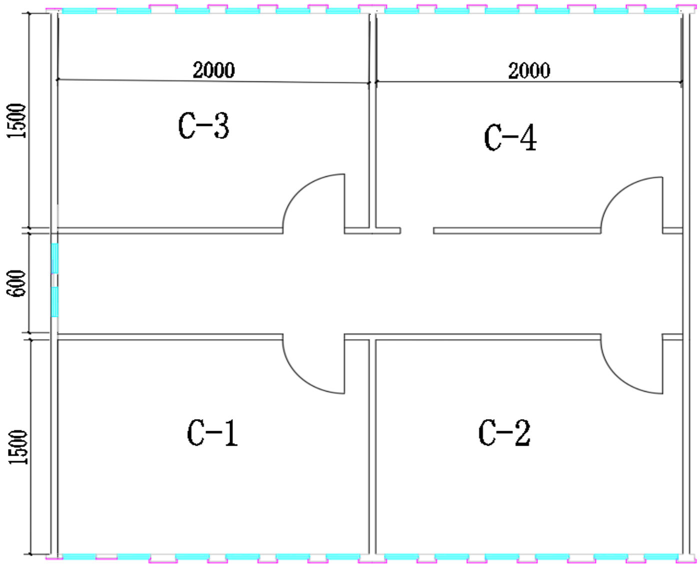

Figure 1: Schematic diagram of the building plane plan

2.1 Experimental Conditions Setting

The experimental conditions were set to three air flow control modes: Natural Ventilation (NF), Fresh Air System (CF), and Air Purifier (FF). The population sample participating in the experiment was divided into three age groups: 2MET (15-35 years old), 3MET (35-45 years old), and 6MET (45-60 years old). The ventilation rate for each group was controlled at approximately 10 L/s per person. Meanwhile, the whole-house temperatures were set at four different environmental temperatures: 20°C, 22°C, 24°C, and 26°C. The air humidity was controlled within the range of 60% to 70%[2].

2.2 Questionnaire Survey Design

The questionnaire survey was conducted at fixed time intervals, sampling participants regularly to ensure timely acquisition of their real feedback. In the questionnaire, participants rated their thermal sensation (TS), thermal acceptability (TA), airspeed acceptability (AMA), perceived air quality (PAQ), thermal preference (TP), and airspeed preference (AMP). To ensure the accuracy and validity of the survey results, special attention was paid to the questionnaire design and instructions for each indicator. For detailed content, please refer to Table 1.

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Table 1: The parameter assignment and description of various indicators in the questionnaire survey

Number	Index	Assignment and parameters
1	Thermal sensation (TS)	-4 very cold, -3 cold, -2 cool, -1 slightly cool, 0 neutral, 1 slightly warmer, 2 warm, 3 hot, 4 very hot
2	Thermal acceptability(TA)	Positive (0.01 "just acceptable" ~4 "very acceptable") indicates satisfaction, Negative value (-0.01 "just acceptable" ~ -4 "very unacceptable") indicates dissatisfaction.
3	Wind speed acceptance(AMA)	Positive (0.01 "just acceptable" ~4 "very acceptable") indicates satisfaction, Negative value (-0.01 "just acceptable" ~ -4 "very unacceptable") indicates dissatisfaction.
4	Perceive air quality(PAQ)	Positive (0.01 "just acceptable" ~4 "very acceptable") indicates satisfaction, Negative value (-0.01 "just acceptable" ~ -4 "very unacceptable") indicates dissatisfaction.
5	Hot preference(TP)	-1 Want colder, 0 the same, 1 warmer
6	Wind speed preference(AMP)	-1 less airflow, 0 remains the same, 1 more airflow.

2.3 Experimental and Questionnaire Result Statistical Analysis

2.3.1 Analysis of Airflow Speed

Figure 2a illustrates the satisfaction level of participants with different airflow speeds under various test conditions. In the 2MET (15-35 years old) group, participants tended to choose lower wind speeds, which gradually increased with rising temperatures. At 22°C, the chosen wind speed was 0.45 m/s, increasing to 0.66 m/s at 24°C, and further to 1.17 m/s at 26°C. Participants in the 4MET (35-45 years old) group showed a similar trend in wind speed selection at different temperatures. At 20°C and 22°C, the chosen wind speeds were 0.35 m/s and 0.7 m/s, respectively, and increased to 1.08 m/s and 1.61 m/s at 24°C and 26°C. In the 6MET (45-60 years old) group, wind speed selection continued to increase at all temperatures, reaching 1.17 m/s, 1.66 m/s, 1.79 m/s, and 1.85 m/s, respectively. Figure 2b depicts participants' thermal comfort under different test conditions, showing that participants maintained good comfort under all temperature conditions with airflow[3].

Figure 3a displays the acceptability and preference choices of participants for wind speed under different test conditions. Under the same wind speed condition, in the 2MET (15-35 years old) group, 95% of participants could accept it; in the 4MET (35-45 years old) group, 85% could accept it; and in the 6MET (45-60 years old) group, only 20% could accept it. Acceptance significantly decreased with increasing age for the same wind speed. Figure 3b shows the preference for wind speed. Participants in the 2MET (15-35 years old) group generally did not need to change the wind speed, but as age increased, 80% of participants wished for an increase in wind speed, with 20% indicating a need for even higher speeds.

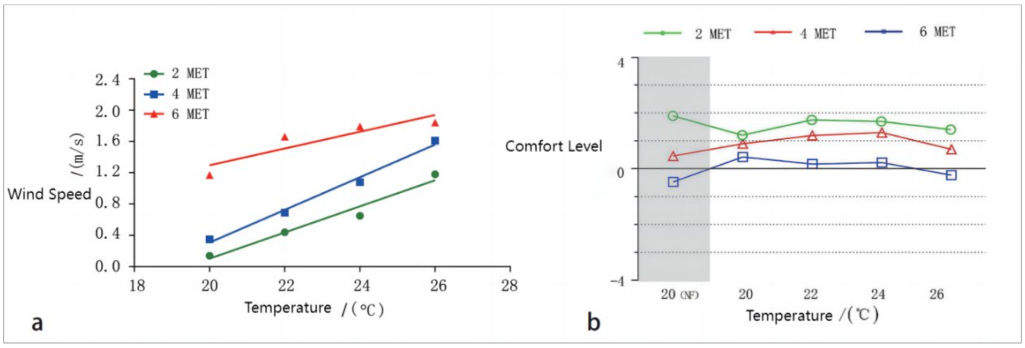

Figure 2: Preference wind speed and thermal comfort voting of the subjects under different test conditions

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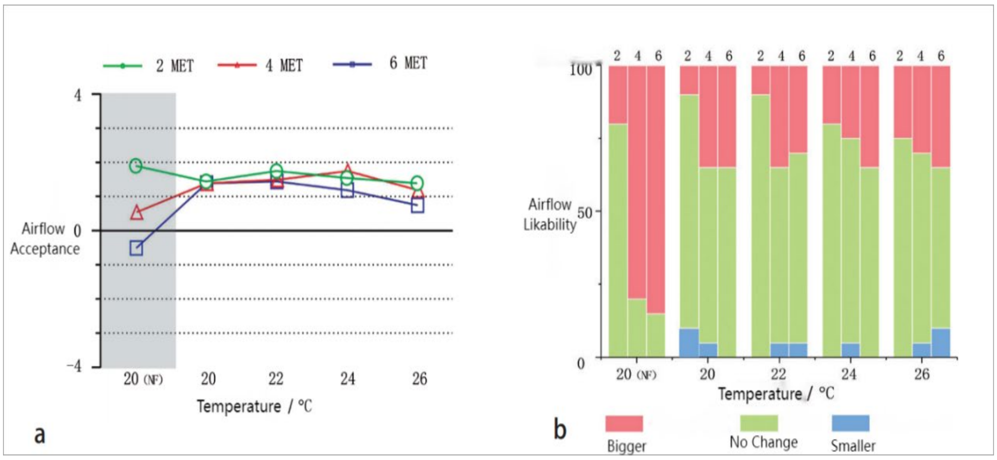

Figure 3: Flow acceptance and percent airflow preference under different test conditions

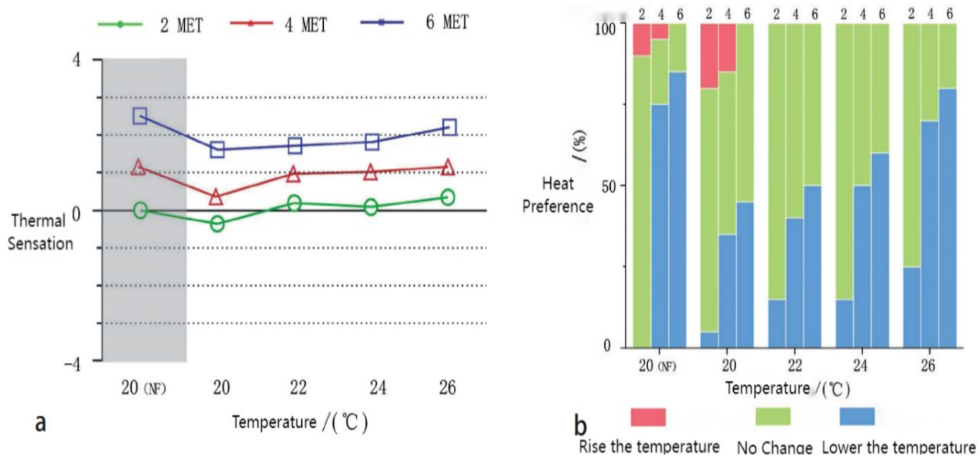

Figure 4: Percentage of thermal sensation and thermal preference under different test conditions

2.3.2 Analysis of Thermal Sensation

Figure 4a presents participants' evaluations of thermal sensation (TS) under different test conditions. Compared with the initial temperature sensation at 20°C, the 2MET (15-35) group's thermal sensation remained in the middle range for all temperature conditions, with no significant difference from the initial thermal sensation. However, in the 4MET (35-45) group, participants' votes were concentrated between "slightly warm" and "warm." Notably, most participants in the 6MET (45-60) group chose the "hot" interval, indicating a significant difference in thermal sensation. Additionally, Figure 4b shows the percentage of votes for participants' thermal preference (TP), revealing a close relationship between TP and TS. In the 2MET (15-35) group, participants typically chose "no change" and tended to select lower temperatures as the sensation became warmer. In both the 4MET and 6MET groups, regardless of the current room temperature, participants' temperature preferences were lower than the 20°C condition under natural ventilation.

In summary, as age increases, participants' thermal sensation in high-temperature environments gradually intensifies. Meanwhile, participants' choices for thermal preference also exhibit a similar trend. These results are essential for understanding the perception and needs of different age groups regarding temperature.

2.3.3 Comparative Analysis of Two Airflow Organization Methods

Table 2 compares the experimental and questionnaire result data of Natural Ventilation (NF), Fresh Air System (CF), and Air Purifier (FF) under different conditions. Compared to natural ventilation, the effectiveness in the 2MET (15-35) group is lower, but its acceptability remains close in the 4MET and 6MET groups. Compared to the Fresh Air System, the Air Purifier generates slightly higher thermal sensations (TS), lower thermal acceptability (TA), and lower airflow acceptability (AMA), with most differences not being significant. Overall, under 4MET and 6MET conditions, the satisfaction with the Air Purifier is significantly lower than that with the Fresh Air System.

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Table 2: Experimental and questionnaire results of natural ventilation NF, fresh air system CF and air purifier FF under different conditions

	2MET			4MET			6MET		
	20NF	26CF	26FF	20NF	26CF	26FF	20NF	26CF	26FF
TS	0.2(0.8)	0.3(0.9)	0.6(1.1)	1.1(1.0)	1.1(0.8)	1.5(1.0)	2.4(0.6)	2.2(1.0)	2.2(0.8)
TA	2.2(1.0)	1.8(1.1)	1.2(1.4)	1.3(1.1)	1.0(1.0)	0.6(1.6)	0.1(1.5)	0.3(1.2)	-0.2(1.6)
PS	100%	94%	89%	89%	89%	67%	55%	67%	55%
AMA	1.9(1.0)	1.4(1.2)	1.2(1.6)	0.5(1.2)	1.4(1.3)	0.4(1.6)	-0.4(1.8)	0.6(1.2)	0.1(1.8)
PAQ	2.5(1.1)	1.8(1.3)	1.4(1.5)	1.6(1.6)	1.6(1.6)	1.4(1.6)	1.0(2.0)	1.3(1.5)	1.1(1.8)

3. Conclusion and Implications

Based on the analysis of the experimental results, the method of air regulation plays a positive role in adjusting the thermal comfort perception of individuals across different age groups. The specific conclusions drawn from the experiments are as follows:

3.1 Importance of Environmental Temperature

The results indicate that airflow, through the evaporative effect on the skin, regulates body temperature. Even when the room temperature reaches 26°C, the human comfort level remains no lower than at 20°C. In residential buildings, improving thermal comfort through airflow can effectively prevent heat discomfort for individuals of different age groups.

3.2 Significance of Providing Uniform Airflow

In terms of airflow organization, the Fresh Air System can provide more uniform airflow and suitable temperatures. For residential buildings, adopting the airflow organization form of the Fresh Air System, which delivers air closer to the human body, is more conducive to even distribution, ensuring airflow comfort.

3.3 Choice of Airflow Organization Form

The small and dispersed air outlets of the Fresh Air System can lead to issues such as uneven indoor temperature fields and differences in comfort near the outlets. To address these problems, integrating and coordinating natural ventilation with the Fresh Air System can be considered. On the one hand, natural ventilation can accelerate the diffusion and mixing of various airflows, avoiding issues associated with direct airflow from the Fresh Air System outlets. On the other hand, by achieving conditions of approximate comfort, it is possible to reduce the temperature adjustment amount and operating time of the Fresh Air System, significantly lowering energy consumption.

In summary, by judiciously selecting air regulation methods, it is possible to effectively adjust the thermal comfort perception of individuals across different age groups. In residential buildings, improving environmental thermal comfort through airflow can mitigate heat discomfort for individuals of various ages. Simultaneously, when choosing the airflow organization form, considerations should be given to issues of even distribution and comfort.

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