Field study on thermal environment and thermal adaptability of classrooms in Hefei area universities

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Abstract. In order to study the thermal environment and thermal comfort of university classrooms, a long-term on-site study of a university classroom in the Hefei area is carried out by combining questionnaires and on-site data collection. A thermal sensory model applicable to the university classroom in the Hefei area is established, and through analysis it is found that the measured thermal neutral temperature is lower than the predicted thermal neutral temperature under the PMV model, and the corresponding 90% acceptable temperature ranges under the measured and PMV models are 22.0~25.6°C and 17.2-24.9°C respectively. Opening and closing doors and windows and adding and removing clothing are the preferred thermal adaptive behaviors of the subjects when the indoor thermal environment changes.

1. Introduction

With the continuous development of society and economy, people's requirements for indoor environmental quality are becoming higher and higher, and creating a comfortable and healthy indoor environment has become an urgent need for occupants. As the main place for students to study in class, the thermal environment of the classroom will directly affect the normal study life of students, so it is necessary to study the thermal environment and thermal comfort of the classroom in colleges and universities.

So far, many domestic and foreign experts have done a lot of research on thermal comfort in college classrooms. Jung investigated the thermal environment and thermal comfort in Korean college classrooms and concluded that people could accept a slightly warmer indoor environment but not a colder indoor environment [1]; Singh et al concluded that the thermal neutral temperature in Indian colleges and universities in summer and winter was 29.8 °C, and people adjusted their thermal sensation by adding or removing clothing, controlling the opening of windows and controlling the opening of fans [2]; Zhu WB et al. conducted a field study on the thermal comfort of university students in a centrally heated classroom in a cold region and found that 80% of the subjects' acceptable temperature range was wider than the temperature range specified in ASHRAE 55 [3]; Li M et al. conducted a long-term study on the thermal comfort of university classrooms in Beijing. The results showed that there were differences in people's needs for indoor environment in different seasons [4].
At present, there is a lack of research on thermal comfort and thermal adaptation of university classrooms under natural ventilation in hot-summer and cold-winter zone. As a representative city in the hot-summer and cold-winter zone, the study of thermal environment and thermal adaptation of a university classroom in Hefei will help to evaluate the thermal environment and thermal comfort of a university classroom in the hot-summer and cold-winter zone, and also provide a reference for subsequent thermal adaptation studies. Therefore, this study selects university classrooms in Hefei for a long-term field study and through the establishment of relevant models to evaluate the thermal environment and thermal comfort of university classrooms.

2. Research method

2.1 Questionnaires

In this research, the classroom of a university in Hefei is selected as the research site, and a longitudinal research method is adopted [5]. The selected subjects are some students of a university in the Hefei area, mainly aged 19-21, who have lived in the Hefei area for more than one year and had a strong adaptation to the local climate. The research period is from October to December 2020 and from March to April 2021. The research is conducted during the class period, each class is divided into two small periods each period is 45 minutes and the time of class recess is 5 minutes. Also, in order to avoid the influence of the subjects' activity status in the first 30 minutes on the questionnaire results, the questionnaire is distributed between classes for each test. The questionnaires mainly include basic information about the subjects and the hot sensation poll, in which the ASHARE 7-point scale is used: very hot (+3); hot (+2); slightly hot (+1); moderate (0); slightly cold (-1); cold (-2); very cold (-3). A total of 996 questionnaires are returned for the whole period, with 941 valid questionnaires, of which 533 are for males. 408 are females.

2.2 Field data collection

The field data collection mainly includes the collection of temperature, relative humidity and airflow velocity in the classroom. The instruments are shown in the diagram below and all comply with the requirements of ISO 7726. The instruments are placed 1.1m above the floor in the center of the classroom and are positioned against the wall, away from solar radiation and other heat sources.
Table 1. Instrument models and parameters.

| Instrument name                  | Model   | Measurement parameters     | Measurement accuracy | Scope        |
|----------------------------------|---------|----------------------------|----------------------|--------------|
| Black ball thermometer           | JTR04   | black ball temperature     | ±0.5°C               | -20-125°C    |
| Temperature and humidity loggers | GSP-8A  | temperature               | ±0.3°C               | -20-40°C     |
| Wind speed testers               | EC-A2 ultrasonic wind direction and speed sensor | air flow velocity   | ±0.2m/s          | 0-60m/s      |

3. Test results and data analysis

3.1 Indoor thermal environment parameters

The trends of temperature and humidity changes in the classroom during the research period are analyzed and the results are shown in Table 2. It can be seen that the average air temperature and the average relative humidity in the classroom during the research period varied from 14.1°C to 22.4°C and 41.5% to 54.5%, respectively, with an average value of 19.7°C and 47.66%, respectively. It conforms to the mild climate and high humidity in Hefei area. Due to the better airtight of the classroom, the classroom is basically in a calm state in the process of investigation.

Table 2. Indoor thermal environment parameters of each period.

| Period     | Average indoor air temperature/°C | Average indoor mean radiant temperature/°C | Average indoor relative humidity/°% | Average indoor air flow velocity / (m/s) |
|------------|----------------------------------|---------------------------------------------|-------------------------------------|----------------------------------------|
| October 2020 | 22.3                             | 22.4                                        | 44.8                                | <0.2                                   |
| November 2020 | 20.8                             | 20.8                                        | 43.5                                | <0.2                                   |
| December 2020 | 14.3                             | 14.1                                        | 41.5                                | <0.2                                   |
| March 2021   | 19.4                             | 19.7                                        | 54.0                                | <0.2                                   |
| April 2021   | 21.9                             | 22.0                                        | 54.5                                | <0.2                                   |

3.2 Clothing thermal resistance and operating temperature

Based on the ASHRAE-55 standard, the operating temperature $t_{op}$ is chosen as an indicator of the thermal environment in the classroom for this study. A weighted fit is made by taking the mean of the measured operating temperatures within each interval as the independent variable and the mean of the thermal resistance of the subject's clothing as the dependent variable, with the weights being the ratio of the sample size within each interval to the total sample size, as shown in Figure 4.
The linear fitting equation is also calculated as:

\[ I_{clo} = -0.04t_{op} + 1.62, R^2 = 0.73686 \]  

(1)

It is not difficult to see that there is a negative correlation between the thermal resistance of clothing and the operating temperature in the room. The thermal resistance of clothing decreases by 0.04 clo per litre of operating temperature, which indicates that the participants adjust their clothing characteristics according to the changes in their environment, when the indoor environment can not meet the subjects thermal comfort requirements, the subjects will reduce clothing thermal resistance to adapt to changes in the surrounding environment.

3.3 Thermal sensation and operating temperature

In order to investigate the relationship between Thermal sensation and indoor operating temperature, the Predicted Mean Thermal sensation PMV (Thermal Mean Vote) is calculated by Berkeley Thermal Comfort Tool (CBE). The Actual Mean Thermal Sensation (MTS) and predicted Mean Thermal Sensation (PMV) of the questionnaire are linearly weighted with the operating temperature \( t_{op} \), as shown in Figure 5.

The linear fitting equation is also calculated as:

\[ MTS = 0.12846t_{op} - 2.73793, R^2 = 0.67545 \]  

(2)

\[ PMV = 0.27767t_{op} - 6.67119, R^2 = 0.79992 \]  

(3)

As can be seen from Figure 5, MTS and PMV have a good linear relationship as a whole. Within the operating range of less than 26 °C, MTS is always larger than PMV and closer to neutrality than PMV, which indicates that the subjects have a strong adaptability to the climate in Hefei area, and with
the increase of operating temperature, the two got closer and closer, the deviation is smaller and smaller, and the degree of deviation indicates the effect of thermal adaptation on thermal comfort, indicating that the subjects adjust their thermal perception by adopting adaptive behavior in response to changes in their thermal environment.

3.4 Thermal neutral temperature and acceptable temperature range

According to PMV-PPD model developed by Professor Fanger [6], 90% of people are satisfied with the indoor thermal environment when the thermal sensation value is ±0.50, and 80% of people are satisfied with the indoor thermal environment when the thermal sensation value is ±0.85. Taking ±0.50 and ±0.85 into fitting equations (2) and (3), the 80% acceptable temperature ranges of PMV and MTS are 20.7~26.9 °C, 14.5~27.6 °C, and 90% acceptable temperature ranges are 22.0~25.6 °C and 17.2~24.9 °C respectively. Let PMV=0 and MTS=0 to obtain the thermally neutral temperatures of 23.8°C and 21.1°C respectively.

The thermal neutral temperature corresponding to PMV is higher than that corresponding to MTS, but the acceptable temperature range corresponding to MTS is wider than that corresponding to PMV, which indicates that in the course of the investigation, through the adjustment of thermal adaptation behavior, the acceptability of thermal environment in classroom is further improved. Therefore, the effect of adaptive behavior on actual thermal sensation can not be neglected.

3.5 Statistics on subjects' thermal adaptation behavior

To further explore subjects' heat adaptation, adaptive behaviors such as adding and removing clothing, opening and closing doors and windows, drinking hot drinks, drinking cold drinks and light activity are included in the questionnaire for subjects to choose from, and the frequency of each adaptive behavior is counted.

![Figure 6. Frequency statistics of thermal adaptation behavior.](image)

It can be seen from the figure 6 that the frequency of opening and closing doors and windows, adding and removing clothes is higher than other thermal adaptation behaviors, which indicates that when the indoor environment can not meet the thermal comfort needs of human body, the opening and closing doors and windows and adding and removing clothes are the main ways in which subjects regulate themselves.

4. Conclusions

(1) There is a negative correlation between thermal resistance of clothing and indoor operation temperature, and the thermal resistance of clothing decreases by 0.04 clo per liter of operation temperature, reflecting the adaptive characteristics of the garments as the subjects adjust to the
changing environment they are in.

(2) PMV and MTS are positively correlated with operating temperature, with the measured thermoneutral temperature of 21.1°C lower than the predicted thermoneutral temperature of 23.8°C, but the measured acceptable temperature range is wider than the predicted acceptable temperature range.

(3) When the indoor temperature changes, people tend to be more inclined to open and close doors and windows, add and remove clothes to adjust their thermal feeling, so as to adapt to the change of the surrounding environment.

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