Students Responses to Thermal Environments in University Classrooms in Zunyi, China

Jing Liu1,*, Qing Luo2 and Ting Cai3
1 School of Engineering, Zunyi Normal University, Zunyi 563002, China
2 School of Urban Construction and Environmental Engineering, Chongqing University, Chongqing 400044, China
3 School of Management, Zunyi Normal University, Zunyi 563002, China
*jimlau@vip.126.com

Abstract. Indoor thermal environment has significant influence on occupants’ working efficiency, study performance and well-being, particularly in space with high population density but no HVAC system. Therefore, in order to understand the indoor thermal environmental conditions and subjects’ interactions with ambient physical environment, a field study was carried out during winter time in naturally ventilated classrooms in Zunyi, China. The range of indoor air temperature variation during investigation period, 11.57°C to 19.80°C, was not within the thermal comfort zone recommended by ASHRAE 55 Standard. Nearly 80% of occupants regarded indoor thermal condition as ‘slight cool’ and ‘cool’, and wanted indoor environment to be warmer as a consequence. The thermal neutral temperature, acceptable range and thermal sensitivity under AMV model were 20.27°C, 16.60-23.95°C and 4.33°C/unit, respectively. People’s clothing adjustment followed the tendency that the mean values of clothing insulation decreased gradually with indoor air temperature increasing. The discrepancies of subjects’ thermal sensations, thermal neutral temperatures, thermal acceptable temperature zone and thermal sensitivity reflected the adaptations of occupants in response to ambient thermal stimuli. Due to the more tolerance of cold environment revealed in this study, the energy used for space heating would be reduced to some extent. The findings obtained from this investigation also provide guidelines on building refurbishment, maintenance and new building design.

1. Introduction

Zunyi city is located in northern part of Guizhou Province. It has typical hot summer and cold winter climate. The winter covers the period from December to next February with average outdoor temperature of 5.5°C. Due to the policy reasons, the centralized heating system is not applied in Zunyi. The traditional heating strategy in residential buildings is using iron casting individual stove which is burning coal as heat source. Such heating system, on the one hand, is of lower heat transfer efficiency, on the other hand, emits green-house gas deteriorating the urban heat island effect and further aggravates the occurrence frequency of smog. But in university buildings, no heating systems are available. Meanwhile, very few filed studies on thermal environment and thermal comfort of occupants are conducted here [1-3], even though, many relative researches had been performed in other cities with hot summer and cold winter climate [4-6]. However, according to the thermal comfort theory, the achieved thermal comfort by subjects is a comprehensive result influencing by both physical and non-physical factors. On the basis of heat balance theory [7], thermal comfort is
determined by air temperature, air velocity, relative humidity, mean radiant temperature, metabolic rate and clothing insulation. From the point of view of adaptive thermal comfort, people tend to maintain or restore the thermal comfort by means of performing various adaptive responses [8]. People, thus under certain thermal conditions are no longer passive recipients of ambient thermal stimuli but positive individuals interacting with the person-environment system. The adaptations are divided into three categories [9-10], physiological (genetic adaptation and acclimatization), behavioural (personal, technological or cultural) and psychological (expectation or habituation) dimensions, respectively. As aforementioned, People living in the same thermal environmental may have different thermal sensations due to the discrepancies in past thermal experiences, thermal expectation, socio-economic and cultural issues. Therefore, the international standards regarding thermal comfort in which specification of conditions for thermal comfort is provided cannot be applied directly without corrections.

In order to full understand the thermal environment conditions of university classroom and to assess thermal comfort of students in winter, an investigation was carried out in Zunyi. The results presented are helpful for better understanding of objective thermal environmental status and subjective thermal perceptions, and, moreover, providing guidelines on local university classroom refurbishment and design for new educational buildings with the aim to satisfy occupants’ thermal comfort.

2. Methodology
This field study was performed in winter season covering the period from December to next February. Both questionnaire survey and environmental parameters measurement were employed in this study.

2.1. Questionnaire Survey
Questionnaire used in this investigation comprises background information of subjects, e.g. age, gender, clothing assembles, activity level, length of living in Zunyi; thermal perceptions in terms of thermal sensation, thermal preference, thermal acceptability and satisfaction and thermal expectation; adaptive actions taken by occupants, such as environmental controls operation, clothing changing. The majority of answers were designed as a 7-point or a 5-point scale covering from -3 or -2 to +3 or +2 with the medium value of 0 indicating the neutral state. With respect to the temperature acceptability question, the binary answer, namely acceptable or unacceptable, was used.

2.2. Physical Environmental Parameters Measurement
Air temperature \( T_a \), air velocity \( V_a \), relative humidity (RH) and globe temperature \( T_g \) were measured in this study using hot wire anemometer (TESTO 425), black sphere thermometer (HEAT INDEX CHECKER AZ8778), respectively. Mean radiant temperature was estimated by globe temperature [11-13]. Air temperature and air velocity were measured at the vertical levels of 0.1m, 0.6m and 1.1m for seated people representing the positions of ankle, waist and neck, respectively. The data collecting from three heights then averaged as mean values for further analysis. Relative humidity and globe temperature were measured at the 0.6m level for seated occupants. Both measurement positions and periods in this field study were in accordance with requirements regarding on-site measurements specified in ASHRAE 55 standard [14] and ISO 7726 [15].The environmental variable measurement was applied simultaneously with questionnaire survey.

2.3. General Information of Surveyed Buildings and Subjects
The surveyed buildings in this investigation are naturally ventilated without heating system. They are lecture buildings with north-south orientation, brick-concrete structure and double-glazed windows with aluminium alloy frames.

The survey was carried out 2-3 days per week during winter period. On each survey day, two sessions (morning and afternoon) were included. A total of 178 respondents comprising 125 male and 53 female participated into this investigation. Majority of them were full-time undergraduate students with the age no more than 21-year old, accounting for 87%.
3. Results

3.1. Outdoor and Indoor Climate
The outdoor and indoor environmental variables are presented in Table 1. During the survey period, the outdoor and indoor air temperatures varied from 11.23°C to 18.00°C or 11.57°C to 19.80°C with mean values of 13.21°C and 14.83°C, respectively. Indoor and outdoor air velocities ranged between 0.05 m/s and 2.00 m/s, 0.03 m/s and 0.26 m/s with means of 0.15 m/s and 0.71 m/s, respectively. The ranges of relative humidity were similar covering from 60% to 80% for both indoor and outdoor cases with a mean of 72%. There was around 1°C difference in average value between indoor and outdoor globe temperatures. The indoor air temperatures were not in winter thermal comfort zone, which was specified in ASHRAE 55 Standard. Because the windows in surveyed classrooms were always closed, the mean indoor air velocity was nearly five times lower than mean outdoor air velocity, 0.15 m/s and 0.71 m/s, respectively. The average values of both indoor and outdoor relative humidity were around 72%. The figures presented in tables confirmed with the local cold and humid winter characteristic.

Table 1. Summary of Indoor and Outdoor Environmental Parameters.

| Environmental Parameters | Maximum (Outdoor/Indoor) | Maximum (Outdoor/Indoor) | Maximum (Outdoor/Indoor) | S.D. (Outdoor/Indoor) |
|--------------------------|--------------------------|--------------------------|--------------------------|----------------------|
| $T_a$ (°C)               | 18.00/19.80              | 11.23/11.57              | 13.21/14.83              | 1.59/2.15            |
| $V_a$ (m/s)              | 2.00/0.26                | 0.05/0.03                | 0.71/0.15                | 0.80/0.07            |
| RH (%)                   | 80.40/80.51              | 60.00/65.00              | 72.36/72.50              | 7.61/7.37            |
| $T_g$ (°C)               | 17.90/18.20              | 10.10/10.10              | 11.80/12.45              | 1.75/2.42            |

3.2. Thermal Sensation and Thermal Preferences
Figure 1 shows the distributions of thermal sensation votes and thermal preference votes.

Figure 1. Thermal Sensation Votes and Thermal Preference Votes Distributions.
All occupants in this study regard the indoor thermal environment as ‘just right’, ‘slightly cool’, and ‘cool’, accounting for 23.56%, 59.77% and 16.67%, respectively. No thermal sensation votes are within the warmer three-category in seven-point scale. The distributions of thermal sensation votes (AMV) are in agreement with the phenomenon that there is no heating system installed in surveyed classrooms in local cold-humid winter. In terms of thermal preferences of respondents, it is clear that people who feel indoor thermal environment cooler, the warmer they want surrounding thermal environment changing. For instance, with the thermal sensations changing from cool to just right, the percentages of want the indoor thermal environment warmer (including a bit warmer and much
warmer) drops from 93.0% to 63.0%. Overall, majority of subjects prefer a warmer indoor thermal condition in winter.

### 3.3. The Adaptive of Occupants

In order to identify how occupants adapt to surrounding thermal environment, the variations of Actual Mean Vote (AMV) gathering from questionnaire and Predicted Mean Vote (PMV) calculating on the basis of four environmental variables and two personal factors (clothing insulation and metabolic rate) against each 0.5°C of indoor air temperature are demonstrated in figure 2.

![Figure 2. The Relationship between Thermal sensations and Indoor Air Temperature.](image_url)

As shown in figure 2, the AMV values were higher than PMV values at the same indoor air temperatures. In other words, people actually didn’t feel as cool as predicted under the same thermal conditions. This can be explained that more than 80% of occupants are local people and already get used to local cold and humid winter. As a result, the ‘warmer’ thermal sensation votes were casted by subjects. It also implies that PMV overestimates the effects of lower temperatures on thermal sensations.

The linear relationships between thermal sensations and indoor air temperature are presented as below:

\[
AMV = 0.2312T_a - 4.6869 \quad (R^2 = 0.8959) \quad (1)
\]

\[
PMV = 0.2532T_a - 5.7608 \quad (R^2 = 0.83) \quad (2)
\]

Let AMV=0, PMV=0, the thermal neutral temperatures could be calculated based on equation (1) and (2). Then, the thermal neutral temperatures under AMV model and PMV model were 20.27°C and 22.75°C, respectively. That is to say, respondents are able to achieve thermal neutral status at lower indoor air temperature. This is the result of adaptations in terms of physiological and psychological aspects of occupants. Furthermore, the building energy consumption used for space heating and cooling can be reduced based on the findings. The acceptable temperature range in winter can be derived by letting AMV=±0.85, PMV=±0.85, and then substituting to equation (1) and (2). The acceptable temperature ranges thus were 16.60°C-23.95°C and 19.39°C-26.11°C, respectively. Comparing with thermal comfort zone, 20°C-23.5°C, recommended by ASHRAE 55 Standard[14], the lower limit of comfort zone under AMV model extends more than 3°C. This phenomenon implies that people under naturally ventilated condition can obtain thermal comfort within a wider temperature ranges. On the contrary, the lower limit of thermal comfort zone under PMV model is similar with that specified in ASHRAE Standard. But the upper limit extends around 3°C. As a consequence, the building would consume more energy to increase indoor air temperature to guarantee occupants’ thermal comfort. In addition, the slopes of regression equations also reflect the thermal sensitivity of occupants to physical environmental parameters variations. Based on the equation (1) and (2), the
respondents’ sensitivity to indoor air temperature changes were 4.33°C/unit and 3.95°C/unit, respectively. It means that the changes of indoor air temperature by 4.33°C or 3.95°C will lead to one unit variation of thermal sensations of subjects under AMV and PMV models. Thus, people are more tolerant of ambient air temperature variations under real environment than that predicted by PMV model. The discrepancies in terms of neutral temperature, thermal comfort temperature range and thermal sensitivity between AMV model and PMV model can be contributed to the reason that as a result of climatic chamber experiments, PMV little considers the adaptations of occupants under real environment but regards subjects as passive recipients of ambient thermal stimuli.

3.4. Clothing Adjustment

In addition to physiological adjustment, which helps subjects to adapt to surrounding thermal environment, the adaptation with respect to behavior dimension is easiest observed and cannot be ignored. Clothing adjustment is one of most popular adaptive actions in response to the changes in the indoor thermal environment. The changes in clothing levels against ambient air temperature variations in winter are depicted in figure 3.

![Figure 3. Clothing Insulation Tendencies and Indoor Air Temperature.](image)

The mean value of clothing insulation is 1.0clo varying from 0.75-1.23clo during investigation period. More than half (59%) of subjects’ clothing insulation values are within the range of 0.95-1.10 clo, which is in accordance with local cold and humid climatic characteristic in winter. The changes in clothing insulation values with indoor air temperature follow the tendency that with increasing indoor air temperature, the mean values of clothing insulation decrease gradually.

4. Conclusions

This study investigates the thermal environment and adaptive thermal comfort in naturally ventilated classrooms in Zunyi. The findings obtained from this field study are summarized as below:

- The indoor thermal environment is poor in Zunyi. Indoor air temperatures vary from 11.57°C to 19.80°C with mean value of 14.83°C. It is not within the range of thermal comfort zone recommended by ASHRAE 55 Standard.
- Due to no heating system in surveyed buildings, early 80% of occupants (76.44%) regard the indoor thermal environment as either ‘slightly cool’, or ‘cool’. As a consequence, majority of subjects prefer a warmer indoor thermal condition in winter.
- Thermal neutral temperature (20.27°C V.S. 22.75°C) and lower limit of thermal comfort zone (16.60°C V.S. 19.39°C) under AMV model are lower than that under PMV model. On the other hand, the thermal sensitivity (4.33°C/unit V.S. 3.95°C/unit) is not as high as that under PMV model. Such discrepancies reflect adaptations of occupants.
More than half (59%) of subjects’ clothing insulation values are within the range of 0.95-1.10 clo. The tendency of clothing insulation values variations in response to indoor air temperature is that with increasing indoor air temperature, the mean values of clothing insulation decrease gradually.

Acknowledgement
This work was financially supported by Department of Science and Technology of Guizhou Province, China (grant number [2017]1203), by Guizhou Innovative Experts Program (grant number [2017]27) and by Zunyi Normal University’s Doctoral Program (grant number BS[2016]04).

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