Occupants' Responses to Naturally Ventilated Buildings in Northern Guizhou, China

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Abstract. With the acceleration of urbanization, suggestions that are based on findings gathering from field studies on building refurbishment, new building design and building operation and maintenance are essential to achieve building energy saving and carbon emission target. Therefore, a field investigation on thermal comfort and adaptive responses of occupants in naturally ventilated buildings were conducted during winter time in Zunyi. Without central heating system supply, the mean value of indoor air temperature is 14.86 °C. But more than half of occupants (57.9%) who were satisfied with surrounding thermal environment. People are active to utilize various strategies to restore thermal comfort of their own. Adjusting clothing levels and using heating devices (e.g. fan heater, portable hand warmer, etc.) are the most popular adaptive behaviours helping them alleviate thermal discomfort caused by lower and humid thermal environment. The aPMV model is developed with adaptive coefficient of -0.33. The findings obtained from this investigation fill gaps in similar researches in northern Guizhou and provide guidelines on building indoor thermal environment improvement considering passive design strategies in this area.

1. Introduction
The innovation of adaptive thermal comfort theory is that it takes into account the adaptations of occupants [1][2], particularly under non-air-conditioned space, and therefore to be regarded as a better tool to evaluate indoor thermal comfort comparing with traditional heat balance theory. Guizhou province is located in southwest in China and is a traditional undeveloped mountainous area. For a long time, there is little investigation on indoor thermal environment and thermal comfort of occupants has been performed in this area. As a result, in response to the aim of building energy saving and carbon emission reduction, no data gathering from field studies was available for analysis and consequently no practical guidelines on building refurbishment, new building design and building system maintenance could be provided.

In order to evaluate the quality of indoor thermal environment in Guizhou and to fully understand how people would like to response to the variation of ambient thermal environment, an investigation on thermal environment and thermal comfort was carried out in naturally ventilated educational buildings in Zunyi, Guizhou Province covering the period from December, 2018 to February, 2019.

2. Methodology
There are mainly two methods employed in this study, questionnaire survey regarding subjective thermal perception, such as thermal sensation, thermal acceptability and satisfaction, and environmental parameters measurement including air temperature, air velocity, mean radiate
temperature and relative humidity, respectively. Questionnaire survey and environmental measurement are performed simultaneously, 2-3 days each week. The methods used in current study are in agreement with the requirements on questionnaire design, environmental variable measurement specified in ASHRAE 55 [3] standard and ISO7726 [4].

3. Results and Analysis

3.1. Basic information
A total of 1165 valid questionnaire were collected including 480 males of 685 females. The subjects with ages from 17 to 47 years old participated into this study. The mean values of height and weight were 1.65m and 58.7kg, respectively. They all have been living in Zunyi for more than 4 years. It indicates that all occupants have acclimatized local climate.

In terms of indoor thermal environment, the average values of indoor air temperature, air velocity and relative humidity during survey period were 14.83 ℃, 0.15m/s and 72.50%, respectively. Apparently, they were not within the recommended thermal comfort ranges specified in ASHRAE 55 standard [3]. Meanwhile, the real indoor thermal condition is in accordance with local cold and humid climate.

3.2. Thermal perceptions

3.2.1. Thermal sensations. Subjects’ thermal sensations were quantified by thermal sensation vote using 7-point scale covering from ‘-3 cold’ to ‘+3 hot’ with mediate value of ‘0 just right’ in questionnaire. 11.8% and 26.4% of respondents regarded indoor thermal environment as ‘cool’ and ‘cold’, respectively, which was agreement with lower indoor air temperature condition in Zunyi. Only 3.9% of subjects sensed indoor thermal condition as ‘warm’ and no occupants voted ‘hot’. However, if the votes within the central three categories were regarded as ‘comfort’. There were more than half of occupants (57.9%) who were satisfied with surrounding thermal environment.

3.2.2. Thermal acceptability and satisfaction. Even though the indoor thermal condition was poor in Zunyi, 77.6% of participates viewed indoor thermal environment as ‘acceptable’. The corresponding satisfaction rate was 58.2%. It implied that occupants had acclimatized to local cold and humid climate in winter and accepted cold thermal environment.

3.3. Adaptive responses

3.3.1. Personal adjustment. Personal adjustment is usually defined as the adaptive responses in terms of adjusting clothing levels, changing activity level and taking hot or cold drinks. In this study, the personal adjustment was embodied by clothing insulation values varying with surrounding air temperature, as shown in figure 1. it was clearly that occupants’ clothing insulation values decreased constantly with the increasing in indoor air temperature, changing from 1.14clo to 0.92clo in response to the indoor air temperature varyin from 12 ℃ to 17 ℃. With the further rising of indoor air temperature from 18 ℃ to 20 ℃, the changes in values of clothing insulaiton were not significant, but fluctuated around 0.90clo. Such tendency is in accordance with similar researches which were also conducted in hot summer and cold winter zone in China [5][6].

3.3.2. Technical adjustment. Technical adjustment comprises the adaptive behaviours (e.g. turning on heating devices, air conditioners and cooling fan, etc.) utilizing by occupants to adjust surrounding thermal condition to satisfy occupants themselves. The use frequencies of environmental controls during the survey were investigated in this study. Turning on fan heater/portable hand warmer was the most popular behavioural adaptation in winter in Zunyi, accounting for 90.7%. Around 1/3 of subjects would like to open window in winter. But the purpose of window opening behaviour was for fresh air
rather than adjusting indoor air temperature. Half of respondents used blinds/curtain to block glare caused by direct sunlight during survey period.

3.4. Adaptive Predicted Mean Vote (aPMV) model

The aPMV model in the form of \( aPMV = \frac{PMV}{1 + \lambda PMV} \) was first developed by Prof. Yao on the basis of ‘black box’ theory [7]. Comparing with PMV model, the advantages of aPMV model are in that it improve the accuracy of PMV model when predicting occupants’ thermal sensations under non-air-conditioned building by taking into three categories of adaptations. By importing adaptive coefficient \( \lambda \), the influence of subjects’ adaptations on thermal perceptions could be understand from the point of view of quantity. In order to evaluate the effects of adaptations on thermal comfort in this study, the value of \( \lambda \) was calculated by applying least square method, and aPMV model applicable to Zunyi was then developed, as shown in equation (1).

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aPMV = \frac{PMV}{1 - 0.33 \times PMV}
\]  

(1)

In order to verify the developed aPMV model, Actual Mean Vote (AMV), Predicted Mean Vote (PMV) and aPMV were plotted in figure 2 as a function of indoor air temperature. The values of aPMV were closer to actual ones (AMV).

4. Conclusions

A field investigation on occupants’ thermal perceptions and adaptive responses in naturally ventilated educational buildings was carried out in Zunyi during winter times. It fills the gap where there is no
relevant research in northern Guizhou and provides data-based guidelines on indoor thermal environment improvement in this area. The findings in this study are as below:

- The indoor real thermal condition in naturally ventilated buildings is poor. Without effective heating strategy indoor thermal environment is below the lower limit of recommended thermal comfort zone in ASHRAE standard.
- Although poor indoor thermal condition, more than half of respondents accept or are satisfied with surround thermal condition in winter, accounting for 77.6% and 58.2%, respectively. It implies that the adaptation plays a key role of alleviating the thermal discomfort caused by ambient lower temperature.
- Subjects in naturally ventilated buildings in Zunyi are active to utilize behavioural adaptation in terms of personal and technical adjustments, particularly the changing clothing insulation and using heating devices, to help themselves to adapt to ambient thermal environment or to adjust surrounding thermal condition to restore thermal comfort of their own.
- The adaptive coefficient $\lambda$ for Zunyi case is -0.33 and the aPMV model for naturally ventilated buildings in Zunyi is also developed.

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