Analysis on Human Adaptive Levels in Different Kinds of Indoor Thermal Environment

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Abstract

To reveal the law of human adaptive level changing along with indoor temperature and humidity in naturally ventilated buildings, an approach of field survey of thermal comfort has been carried out in an university of Guangzhou for about a year, and adaptive coefficient (λ) proposed in adaptive PMV model (aPMV) has been used to calculate the level of adaptation in different combination of indoor temperature and humidity. The results show that, the effects of different combinations of indoor temperature and humidity on human adaptive level vary from each other obviously, the level of adaptation in cool and dry environment (CDE) and comfortable environment (CE, PMV<0) was low, but it is high in hot and humid environment (HHE) and CE (PMV>0). The adaptive coefficient (λ) are 0.64 (HHE), -0.06(CE, PMV<0), 1.07(CE, PMV>0) and -0.37 (CHE), respectively.

Keywords: indoor thermal environment; adaptive coefficient (λ); adaptive PMV model; thermal sensation

1. Introduction

Thermal comfort is an important aspect of residential buildings other than the usual safety and security aspects [1]. With strong desire of more comfortable indoor thermal environment, the research of thermal comfort evaluation indices has been brought to more and more scholars. Two kinds of approach exist in contemporary thermal comfort research: they are heat balance models based on laboratory studies and adaptive models based on field studies. As is known to all, the PMV-PPD method put forward by Fanger was established by using steady-state heat balance...
method in artificial climate chamber, which was considered to ignore the psychological dimensions of adaptation, social and cultural aspects of an occupant, which are otherwise so prominent in any naturally ventilated buildings. Lately, it was found that the results obtained by this method worked fairly well for conditioned buildings and deviated widely when applied to naturally ventilated buildings [2, 3, 4]. The adaptive thermal comfort model [5] put forward by ASHRAE RP-884 project [6] pointed out that thermal comfort is affected by the psychology, physiology and behavior, it well explains the deviation. So there is a great need to carry out an in-depth study on the adaptive model both theoretically and practically. It is to be hoped that the adaptive model can be based on a theory which has been successfully tested against wide-ranging empirical results. de Dear claimed that the adaptive and heat balance approaches to modeling thermal comfort are complementary rather than contradictory [5]. Therefore some attempts have been made in order to correct the PMV model in the built environment. Fanger and Toftum proposed an extended PMV model which incorporated an ‘expectancy factor, e’, the main factor explaining why PMV overestimates the thermal sensation of occupants in free-running buildings in a warm climate [7]. Yao et al. established the ‘adaptive predicted mean vote’ (aPMV) model by using ‘the black box’ method [8]. Then the least square method [9] has been used to derive the adaptive coefficient in the thermal comfort adaptive model and established the ‘corrected predicted mean vote’ (cPMV) model in different climate zones and seasons by [10]. Zheng et al. used the aPMV model to find out the difference of human adaptive thermal comfort before heating period and after heating period [11]. The aPMV and cPMV model are both using adaptive coefficient to quantify the adaptive level of human.

Most of the residential buildings in hot summer and warm winter zone in China are naturally ventilated buildings. Zhang et al. [12] pointed out that physiological and psychological adaptation can obviously change the range of acceptable temperature in this area. Due to the characteristics of this climate, indoor temperature and relative humidity are considered to be the two of the factors that influence human’s thermal sensation most. Therefore, this paper researched the law of human adaptive level changing along with indoor temperature and humidity in naturally ventilated buildings by using aPMV model which has already been applied in “Evaluation standard for indoor thermal environment in civil buildings (GB/T 2012)” and the results may revise and improve the standard.

2. Methodology

A field study had been conducted in naturally ventilated buildings in Guangzhou of China from May 2008 and lasted for a whole year. The study simultaneously included subjective survey and environmental data monitoring, which were taken among 30 healthy college students (15 males, 15 females) who had already lived there for a long time. The 30 students would do the survey for a whole year in order to weaken the individual differences. The research sites were selected in subjects’ main daily experience buildings, thermal environment physical measurement was in accordance with the international standard.

Indoor and outdoor environment parameters (indoor and outdoor air temperature, relative humidity, velocity and black globe temperature) had been tested. Subjective questionnaire includes respondents’ clothes, activity rate, thermal sensation, humidity sensation vote, airflow sensation vote and so on.

3. Results and analysis

3.1. Thermal sensation

According to Design code for heating ventilation and air conditioning of civil buildings GB 50736-2012, the comfort indoor temperature range is 18-28°C and relative humidity range is 30-70%. In this paper, we define the environment with the temperature higher than 28°C and relative humidity higher than 70% as HHE, and in turn define the environment with the temperature lower than 18°C and relative humidity lower than 30% as CDE. According to the collected data from Guangzhou, the indoor environment can be divided into three conditions to be analyzed, which are CDE, HHE and CE.

The ASHRAE seven-point thermal sensation scale (-3, -2, -1, 0, 1, 2, 3) was used in the survey to help respondents express their own thermal sensation. The mean thermal sensation (MTS) and PMV were then regressed
against the corresponding operate temperature respectively used temperature frequency method [13]. The results are shown in Fig.1 and the linear regression equations are in Table 1.

Table 1. The regression equation of MTS/PMV against top.

<table>
<thead>
<tr>
<th>Indoor environment</th>
<th>MTS Regression equation</th>
<th>PMV Regression equation</th>
<th>MTS R²</th>
<th>PMV R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHE</td>
<td>[MTS = 0.404 \text{top} - 11.35]</td>
<td>[PMV = 0.399 \text{top} - 10.77]</td>
<td>0.854</td>
<td>0.983</td>
</tr>
<tr>
<td>CE</td>
<td>[MTS = 0.215 \text{top} - 5.539]</td>
<td>[PMV = 0.293 \text{top} - 7.421]</td>
<td>0.809</td>
<td>0.967</td>
</tr>
<tr>
<td>CDE</td>
<td>[MTS = 0.349 \text{top} - 8.126]</td>
<td>[PMV = 0.333 \text{top} - 8.086]</td>
<td>0.411</td>
<td>0.514</td>
</tr>
</tbody>
</table>

Figure 1 shows that there are varying degrees of deviation under the three different temperature and humidity indoor environment. PMV values are higher than MTS in HHE but lower in CDE. Under these two situations, PMV line and MTS line are almost parallel. It might because that under relatively extreme thermal environment, adjustments human adopted and its effect are both finite which results in adaptive level being stable. The deviation between PMV and MTS is bigger in HHE than CDE. When in CE, if temperature is relatively low, PMV values are lower than MTS, otherwise, PMV values are higher than MTS. PMV is more sensitive than MTS along with change of temperature. When the temperature becomes high or low, the deviation between PMV and MTS is becoming big but different with environments in high or low temperature and humidity. That means, if the environments become uncomfortable, our adaptive ability can significantly change our thermal sensation. Adaptive levels vary in different temperature and humidity environments because the potential ability to remain comfort is affected by what we can do in the natural ventilation buildings. In order to explain the differences and some laws, this research will compare
and analyze the different adaptive levels in three kinds of indoor environments with different temperature and humidity.

3.2. Results and analysis

Adaptive coefficient (λ) which was proposed in adaptive PMV model (aPMV) by Yao [8] establishes the relationship between the PMV and aPMV in the form of equation (1). There can be three different conditions of adaptive coefficient. When the adaptive coefficient is positive, that means the value of aPMV is lower corresponding to the PMV in warm conditions. At λ<0, that means that aPMV is giving warmer feelings than corresponding PMV. At λ=0, that means the indoor temperature is equal to comfort temperature. This condition is practically impossible but theoretically possible. In this case, the aPMV is equal to PMV.

Substituting the data from the field survey into equation (1),

\[ \text{aPMV} = \frac{\text{PMV}}{1 + \lambda \text{PMV}} \quad (1) \]

Let, \( x = \frac{1}{\text{PMV}} \), \( y = \frac{1}{\text{aPMV}} \)

Then equation (1) can be transformed to:

\[ y = x + \lambda \{ y = f(x) \} \quad (2) \]

A curve with a minimal deviation from all data points is desired. The least squares method is used to fit the sets of data obtained from the field study.

To approximate the given set of data \((x_1, y_1), (x_2, y_2), (x_3, y_3) \ldots \ldots (x_n, y_n)\), the best fitting curve has the least square error, i.e.

\[ \Pi = \sum_{i=1}^{n} [y_i - f(x_i)]^2 = \sum_{i=1}^{n} [y_i - (x_i + \lambda)]^2 = \text{min} \quad (3) \]

Where \( n \) is the number of data sets

To minimize the least square error, let,

\[ \frac{\partial \Pi}{\partial \lambda} = 0 \quad (4) \]

i.e.

\[ \frac{\partial [y_i - (x_i + \lambda)]^2}{\partial \lambda} = 2 \sum_{i=1}^{n} [y_i - x_i - \lambda] = 0 \quad (5) \]

Then,

\[ \lambda = \frac{\sum_{i=1}^{n} (y_i - x_i)}{n} \quad (6) \]

Substituting the data from the yearlong field survey in Guangzhou into these equations, the values of the adaptive coefficient in three different indoor thermal environments are: 0.64 (HHE), -0.06 (CE, PMV<0), 1.07 (CE, PMV>0), -0.37 (CDE), respectively. The diverse of adaptive coefficients shows that adaptive adjustments and adaptive levels are different under different situations. The adaptive level in HHE or in CE (PMV>0) is higher, but lower in CDE and lowest in CE (PMV<0). For the warm and hot weather all the year round in Guangzhou, people might prefer
cool environment, so they hardly not to take adaptive measures in CE (PMV<0). This results in the adaptive coefficient $\lambda$ close to 0. Equation (1) for Guangzhou can be written as equation (7) ~ (10). Figure 2 illustrates the relationships between PMV/MTS against aPMV in Guangzhou.

The dotted lines in Figure 2 express that MTS (or aPMV) equals to PMV, from the figures we can see that in HHE or in CE (PMV>0), the bigger PMV gets, the wider difference value there will be between aPMV and PMV, and it’s bigger than in the other two conditions. That means in warm environment, people are more sensitive to thermal change and more likely to take measures to maintain a comfortable state. In CDE, the smaller PMV gets, the wider difference value there will be between aPMV and PMV, but the deviation is less than in the above two conditions. It indicates that adaptive adjustment and adaptive level is low in this conditions. In CE (PMV<0), aPMV are always similar to PMV, people feel comfortable so they hardly not to take adaptive measures.

Fig.2. Relationship between PMV against MTS/aPMV in different environment

$$aPMV = \frac{PMV}{1+0.64\times PMV} \quad \text{(HHE)}$$  

$$aPMV = \frac{PMV}{1-0.06\times PMV} \quad \text{(CE, PMV<0)}$$  

$$aPMV = \frac{PMV}{1+1.07\times PMV} \quad \text{(CE, PMV>0)}$$  

$$aPMV = \frac{PMV}{1-0.37\times PMV} \quad \text{(CDE)}$$
4. Discussion

The adaptive coefficient $\lambda$, indicating the adaptive level, was well applied in “Evaluation standard for indoor thermal environment in civil buildings (GB/T 2012)” [14]. Such design demonstrates the value of $\lambda$ according to the relationship between PMV and 0. If PMV$\geq$0, then $\lambda$=0.21. While $\lambda$ should be -0.49 when the condition of PMV$<$0 is satisfied. However, even though PMV$\geq$0 (or PMV$<$0), according to the conclusion from this article, $\lambda$ could show a great difference in values due to different indoor temperature and humidity. As a result, the confirmation of $\lambda$, simply resulted from PMV, could not reflect the real and native adaptive level once ignoring practical indoor situation in different areas. Therefore we suggest that, for the evaluation of indoor thermal environment, $\lambda$ should be carefully evaluated based on different situations involving indoor humidity and temperature to avoid the wrong conclusion.

5. Conclusion

Adaptive levels vary in different temperature and humidity environments because the potential ability to remain comfort is affected by what we can do in the natural ventilation buildings.

Adaptive adjustments and adaptive levels vary from different situations. The values of the adaptive coefficient in three different indoor thermal environment are: 0.64 (HHE environment), -0.06(CE and PMV$<$0), 1.07(CE and PMV$>$0), -0.37 (CDE), respectively. The adaptive level in HHE environment or CE (PMV$>$0) is high, but low in the other two environment.

The values of $\lambda$ in standard [14] are ignoring practical indoor situation in different areas. Therefore we suggest that, for the evaluation of indoor thermal environment, $\lambda$ should be carefully evaluated based on different situations involving indoor humidity and temperature.

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References
