E3S Web of Conferences **356**, 03025 (2022)
ROOMVENT 2022
https://doi.org/10.1051/e3sconf/202235603025

Field study on thermal environment and adaptation of workers in winter

Zan Xu[1], *Haiying* Wang[1*], *Baowei* Ge[1], *Jiankai* Li[1], and *Lin* Sun[1]

[1] School of Environment and Municipal Engineering, Qingdao University of Technology, Qingdao, China

Abstract. In order to analyze the thermal environment and its influence on workers' thermal adaptation, a field study was conducted in a rubber factory during winter. Indoor and outdoor environmental parameters were measured and subjective questionnaire surveys were collected. The study was conducted from November to January the next year. During the survey, indoor temperature was in the range of 12.6 to 21.7°C and indoor air velocity ranged from 0.15 to 0.3 m/s. The clothing insulation during heating period was between 0.85-0.9 clo, while it was between 1.21-1.33 clo during pre-heating period. The estimated metabolic rate was around 2-2.2 met. Analysis showed that the thermal sensation vote (TSV) was higher than that predicted by PMV. The neutral temperature difference between TSV and PMV was 4.8°C. The thermal comfort and thermal adaptation of workers in winter were systematically analyzed and a thermal adaptive model was proposed. Basis on the adaptive model, the comfort temperature range of workers was suggested.

1 Introduction

The theoretical research about thermal comfort adaptation in build environment began in the 1970s. de Dear et al. analyzed the ASHRAE RP-884 thermal comfort database in the 1990s and found that the predicted results of people's comfort temperature range were far beyond PMV [1]. On this basis, the theory of thermal adaptation was developed and a related model was proposed, it considers people's own adaptations to the thermal environment.

Because of the diversity of climate and buildings, many researches have explored the thermal adaptation of people in various places. Dong found that people in humid climates were less tolerable to heat and high temperatures than in dry climates [2]. Zhang et al. established a thermal adaptive model in climate of Xi'an, which proposed the relationship between indoor thermal neutral temperature and outdoor air temperature [3]. Gong et al. pointed out that the neutral temperature of Guilin residents in winter was 16.2°C and the expected temperature was 18.6°C [4]. Meng et al. found that PMV of the indoor environment in naturally ventilated office buildings of moderate areas deviated significantly from TSV [5]. Duan et al. found that the acceptable indoor temperature range was 16.5-25.1℃ in college buildings of Shenyang Area [6]. Ji et al. pointed out that the relationship between thermal sensation and operative temperature could reflect thermal adaptation to some extent [7].

Currently, most studies about thermal adaptation were conducted in indoor environments such as classrooms, offices, and homes. The subjects of the studies were mainly students, office workers, and residents with low activity levels, etc. There is a lack of research studies for physically active people such as workshop workers. In this study, a field investigation was conducted in a rubber factory in winter to analyse the thermal environment and thermal adaptation of workers.

2 Methods

The field investigation in this rubber factory has been introduced in previous paper [8], in which investigation during summer and transitional season were reported. The details of investigation methods and procedure in winter were same with that in summer and transitional season, and would not be introduced here due to limited pages.

The winter investigation was conducted in November and January the next year. The following environmental parameters were measured: indoor air temperature, relative humidity, indoor black globe temperature, indoor air velocity and outdoor air temperature. The questionnaires consisted of two parts: basic information survey (gender, permanent residence, height, weight, birth year, actual physical activity type, length of time working in workshop, working hours, current clothing, etc.) and subjective evaluation survey (thermal sensation, thermal comfort, acceptability and overall environmental satisfaction). The ASHRAE seven-point continuous scale was used for thermal sensation vote (-3 cold, -2 cool, -1 slightly cool, 0 neutral, 1 slightly warm, 2 warm, 3 hot)

* Corresponding author: why3305@126.com

[9]. The five-point continuous scale was used for thermal comfort vote (0 comfortable, 1 slightly uncomfortable, 2 uncomfortable, 3 much uncomfortable, 4 intolerable). The five-point scale was used for acceptability vote (1 totally accept, 2 accept, 3 reluctantly accept, 4 not accept, 5 totally not accept) and the four-point scale was used for overall environmental satisfaction vote (1 very satisfied, 2 satisfied, 3 slightly dissatisfied, 4 very dissatisfied)

In total, 40 workers (all the workers in the rubber moulding workshop) participated in the study. Their clothing insulation was collected and determined based on the relevant calculation method in the ASHRAE Handbook [9]. Workers can add or remove clothes pieces under the uniform clothes according to the indoor temperature.

3 Results and analysis

3.1 Results of thermal environment investigation

In winter, outdoor air temperature and indoor air temperature was in the range of -3.7-11.2 °C and 12.6-21.7 °C, respectively. The average indoor air velocity and relative humidity was between 0.15-0.3 m/s and 29.2-40.2%, respectively. About 50% of time, the outdoor temperature was below 0 °C during investigation. For indoor temperature, the temperature conditions higher than 15 °C accounted for 50% of time. The temperature difference between indoor and outdoor during pre-heating period (November) was around 3-4 °C, while it was up to 20 °C or more during heating period (January).

Statistics of clothing insulation showed that during heating period the mean values was between 0.85-0.9 clo, while it was in the range of 1.21-1.33 clo during pre-heating period. As indoor temperature in pre-heating season was lower than that in heating season, workers chose to put more clothes on.

3.2 Subject votes

3.2.1 Thermal comfort, acceptability and overall environmental satisfaction

The results of thermal comfort votes are shown in Fig.1. Workers' thermal comfort increased as the indoor temperature in the workshop increased, with more than 85% of workers finding it comfortable when the indoor temperature was above 0°C. Surprisingly, 80% of workers still found it comfortable during the pre-heating period (when the indoor temperature was below 0°C). This also indicated that workers who work in cold environments for a long time may adapt to the cold environment and have low expectations on the environment.

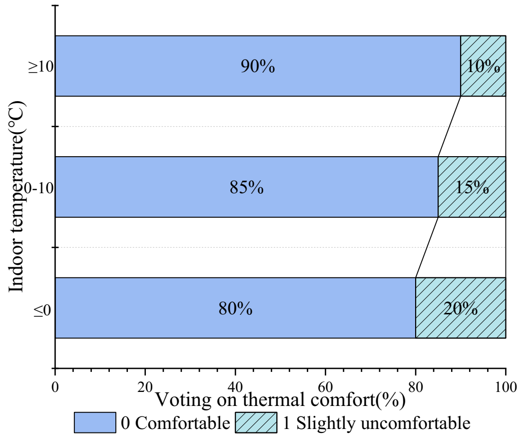

Fig. 1. Thermal comfort votes distribution.

The relationship between thermal comfort vote (TCV) and operative temperature is shown in Fig.2, and the linear regression equation of them is as the following:

$$TCV=0.12871t_0-2.58704 \quad (R^2=0.65821,\ p=0.08677) \tag{1}$$

In this equation, t_0 is the operative temperature.

The workers' thermal comfort increased with the increase of operative temperature. It can also be found that in each working condition investigated, there were workers who voted 0 for thermal comfort, and the vast majority of workers voted between 0 and 1. This implied that almost all workers were comfortable in the winter environment. The linear relationship between thermal comfort and operative temperature was not very significant, probably due to the small sample size and the fact that the study period included both heating and pre-heating periods.

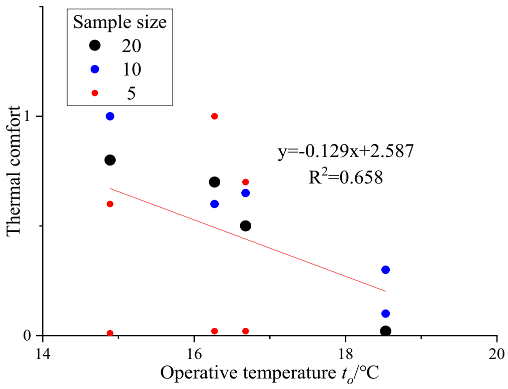

Fig. 2. Relationship between thermal comfort and operative temperature.

Fig.3 shows the PMV model with only the dot at an operating temperature of 18.5°C falling into the comfort zone. Fig.4 shows the ASHRAE thermal adaptive model with all three dots falling into the 90% acceptance range and the dot at an operating temperature of 7.7 falling into the 80% acceptance range.

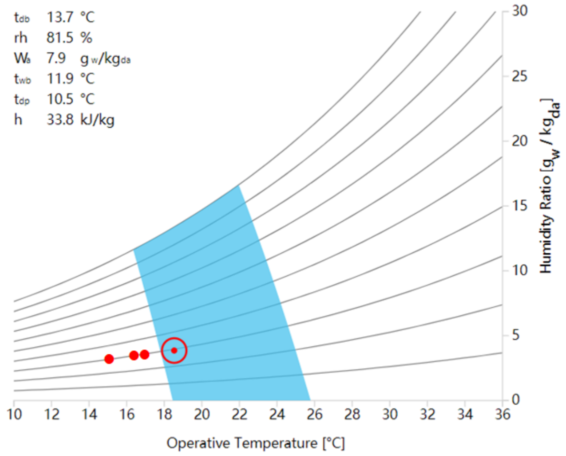

Fig. 3. Measured dots in PMV model.

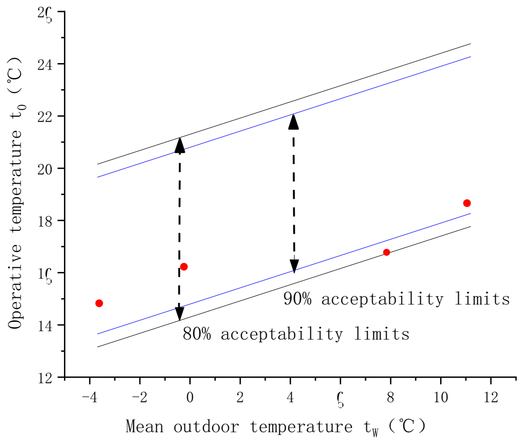

Fig. 4. Measured dots in ASHRAE thermal adaptive model.

The relationship between acceptability and thermal comfort vote (TCV) is shown in Fig.5, and the linear regression equation of them is as the following:

$$TA=0.45221\,TCV+1.00641 \quad (R^2=0.64527,\ p=0.03553) \tag{2}$$

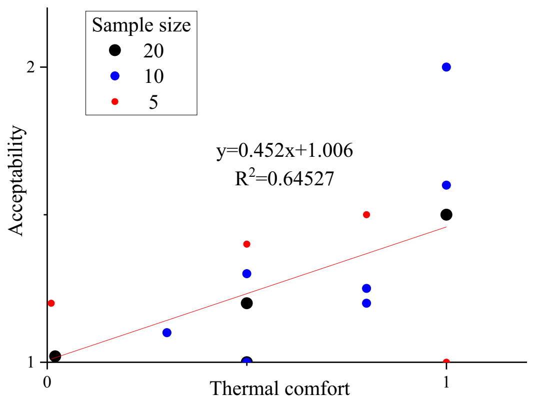

Fig. 5. Relationship between acceptability and thermal comfort.

Fig.6 reflects the relationship between overall environmental satisfaction and operative temperature. During the heating period, the indoor temperature in residential and office buildings is required to be kept above 20°C. However, indoor temperature in workshops is often lower than 20°C due to the large space area and poor wall insulation, etc. From Fig.5 and Fig.6, it can be seen that even though the workshop temperature was lower than other heated buildings, more than 93% of the workers could accept the environment of the workshop in winter. With the increase of operative temperature, workers were more and more satisfied with the overall environment.

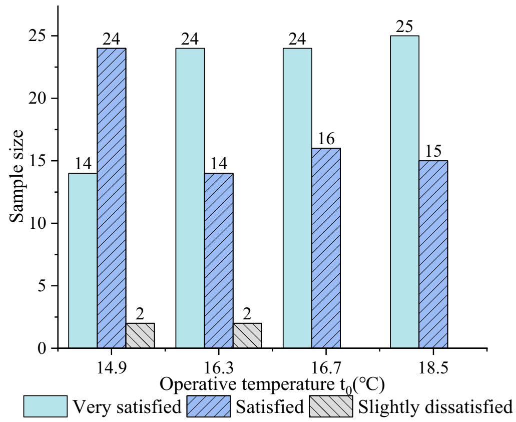

Fig. 6. Relationship between overall environmental satisfaction and operative temperature.

3.2.2 Thermal sensation and thermal comfort

Statistical distributions of the workers' TSV and PMV are summarized in Fig.7. The TSV value basically ranged from -1 to 1, and the largest number of workers felt neutral (voted 0). In general, the workers were acceptable to the indoor environment, and those who felt slightly warm (voted 1) accounted for 22.5% of the overall sample, while the PMV value was distributed at a frequency of 0 at 1. The mean TSV value of -0.08 was slightly higher than the average PMV value of -0.63. PMV underestimated TSV, implying that workers have some tolerance to the cold environment.

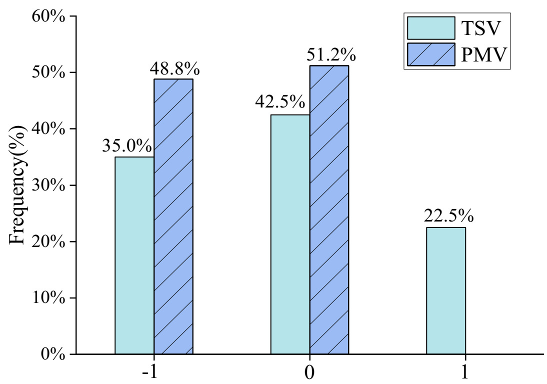

Fig. 7. Distributions of TSV and PMV.

Comparing PMV and TSV during the study period and linearly fitting them with the room operating temperature. The trend of PMV and TSV of workers with operating temperature during the study period is shown in Fig.8, and

 https://doi.org/10.1051/e3sconf/202235603025

the linear regression equations of PMV and TSV are as follows:

$$PMV=0.10232t_0-2.20133 \quad (R^2=0.83722, p=0.0000) \tag{3}$$

$$TSV=0.10433t_0-1.74478 \quad (R^2=0.60489, p=0.0000) \tag{4}$$

From the figure, it can be seen that TSV was always higher than that predicted by PMV, the actual thermal sensation of workers was closer to neutral than the predicted results. Let PMV and TSV be zero in equation (3) and (4), the predicted and measured neutral temperatures of workers during the study period were 21.5°C and 16.7°C, respectively. The PMV predicted neutral temperature was 4.8°C higher than the measured neutral temperature. The comfort temperature range determined according to the ASHRAE PMV model was 17.9-24.9°C.

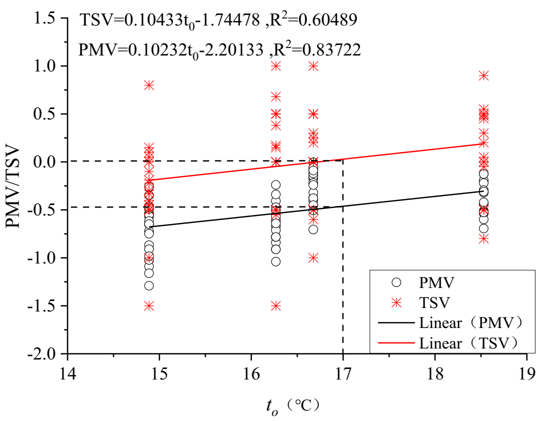

Fig. 8. Change of TSV and PMV with operative temperature.

4 Thermal adaptive model

A systematic study and analysis of thermal comfort was carried out as a basis for establishing a thermal adaptive model in winter (shown in Fig.9). According to the environment in the workshop, there was a linear relationship between indoor comfortable temperature (operating temperature) and mean outdoor air temperature. The linear regression equation of them is as the following:

$$t_0=0.63429t_w+9.5716 \quad (R^2=0.42683, p=0.0000) \tag{5}$$

In this equation, t_w is the mean outdoor air temperature.

This adaptive model can be used to predict and set the indoor thermal environment according to mean outdoor temperature in winter.

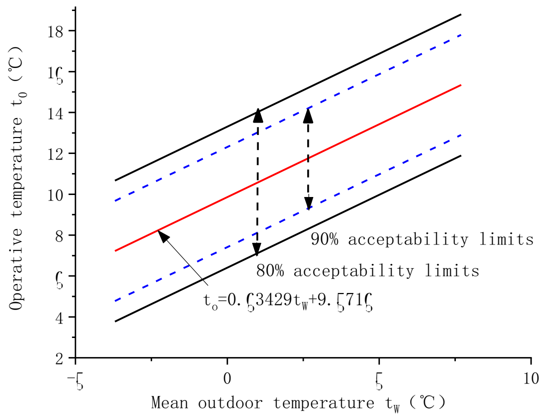

Fig. 9. Thermal adaptive model.

5 Conclusions

During the survey, indoor temperature was in the range of 12.6 to 21.7 °C. The clothing insulation during heating period was between 0.85-0.9 clo, while it was between 1.21-1.33 clo during pre-heating period. Workers were asked to wear uniform clothes and they can add or remove clothes pieces under the uniform clothes according to the indoor temperature. Analysis showed that the thermal sensation vote (TSV) was higher than that predicted by PMV and the neutral temperature difference between PMV and TSV was 4.8 °C. This indicated that workers in this survey adapted to cold environment better than that had been expected by PMV model. Most of the workers could accept the environment of the workshop in winter. A thermal adaptive model was proposed. Basis on the adaptive model, the comfort temperature range of workers under moderate physical activities was suggested, which can be used for the evaluation of indoor thermal environments within the range of similar physical activities and provide theoretical guidance for the design of thermal environments.

The study has been financed by the National Natural Science Foundation of China (No. 51678314).

References

1. R. De Dear, AT, **104**, 94 (1998)
2. M. R. Dong, GT, **23**, 3 (2021)
3. K. G. Zhang, L. J. Wang, P. T. Kong, P. Wang, RAAC, **35**, 5 (2021)
4. X. Z. Gong, C. Chen, C. Y. Jia, JOWUOT, **42**, 7 (2020)
5. Y. Meng, D. Mou, B. Cao, Y. X. Zhu, BEE, **48**, 7 (2020)
6. G. N. Duan, Y. R. Wang, L. Yu, BEE, **38**, 4 (2019)
7. W. J. Ji, B. Cao, Y. X. Zhu, HVAC, **49**, 5 (2019)
8. Z. Xu, H. Y. Wang, J. K. Li, B. W. Ge, L. Sun, *Field investigation on thermal adaptation of workers in a rubber factory*, in Proceedings of ISVAC 2021 and 2021 KIAEBS Autumn Conference, ISHVAC, 24-26 November, Seoul, Korea (2021)
9. *ANSI/ASHRAE Standard 55*, Thermal Environmental Conditions for Human Occupancy, ISSN 1041-2336. (2013)