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Investigating the Ability of Prevailing Thermal Comfort Models to Predict Thermal Comfort in Homes

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Abstract

This paper reports on an investigation of prevailing thermal comfort models (PMV, PMVe and the SCATs model) in terms of their ability to predict thermal comfort in homes. The investigation was based on subjective thermal sensation votes and objective measurements collected over a period of three summer months in 21 single-room private homes. The data suggested that the PMV models underestimate the subjective thermal sensation of the subjects but they cannot be ruled out due to limitations in this study. The SCATs model demonstrated a fairly accurate prediction of the subjective thermal sensation. The reported investigation must be understood as a pilot study on how to gather and analyze data to investigate whether prevailing thermal comfort models are suitable to predict thermal comfort in homes – or whether they should be adjusted to fulfil this purpose.

Keywords – Thermal Comfort; Dwellings; Comfort Models

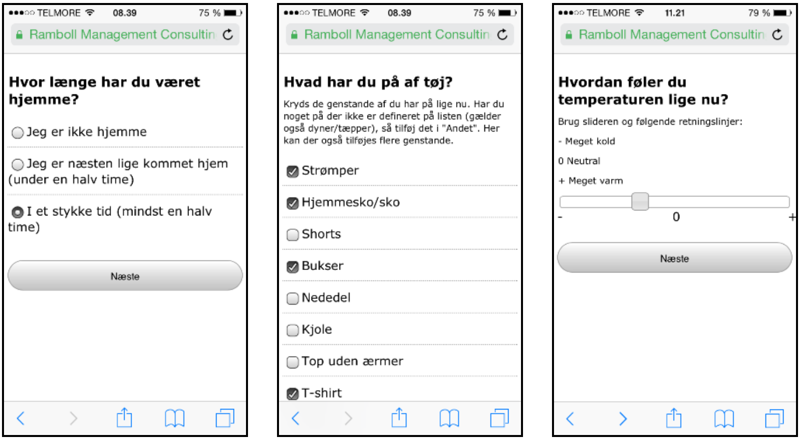
1. Introduction

Occupants in Danish homes considers thermal indoor climate as an important parameter when determining comfort [1]. It is therefore desirable for building designers to have a reliable evaluation model for assessing thermal comfort in homes when predicting performance of design proposals in the early stages of the building design process. The heat balance-based predicted mean vote (PMV) model proposed by Fanger [2] (including the PMVe model [3]), and the adaptive comfort model [4] are currently the two prevailing approaches to predict thermal comfort. The PMV model has been validated for predictions of perceived thermal sensation in mechanical ventilated office buildings [5] but studies have indicated that the PMV model performs unsatisfactory for prediction of thermal comfort in residential buildings [6] and has a tendency to overestimate the perceived thermal neutral state of persons living in warmer climates [7]. The other approach, i.e. adaptive comfort model such as SCATs [4], is deducted from data from office buildings, which immediately questions their validity for predicting thermal comfort in homes.

The lack of validation of the prevailing thermal comfort model as an expression of occupant comfort in homes is critical as these models often are used to set design criteria for residential building design. The establishment of a database for proper validation of the prevailing thermal comfort models as an expression of thermal comfort in homes is therefore needed [5]. The need for this data is the background of the experiment reported on in this paper. The experiment collected subjective votes regarding the thermal comfort in the homes of 21 subjects while logging a range of objectively measurable indoor climate parameters. The data was then compared to the prevailing comfort models PMV, PMVe and the SCATs model.

2. Method

The experiment was conducted at the Grundfos Dormitory in Aarhus, Denmark. A total of 21 students living in single-room apartments participated in the experiment, which was conducted in the summer period from late May to late August 2015. During this period, air temperature and relative humidity in each apartment was logged every 15 minutes using a Tinytag data logger [8]. There was made no attempt to measure the mean radiant temperature, air velocity, or the metabolic rate of the subjects. Calculation of PMV therefore relies on the assumption that the mean radiant temperature was equal to the logged air temperature, that the air velocity was 0.1 m/s, and that the metabolic rate was 1.1 Met for all subjects. However, an analysis of the impact of these estimates on PMV was performed and reported in this paper. Parallel to these objective measurements, the subjects was asked to fill out an online questionnaire. The subjects were prompted to fill out the questionnaire as often as possible when they were home during the experiment. As a reminder, a daily text message with a link to the questionnaire was sent to the subjects once every day. The questionnaire is shown in Fig. 1. The first question asked how long the person had been at home to ensure that the person has adapted to the indoor climate. The subject was only led to the second question concerning the current clothing if he/she had been at home for at least 30 minutes. In the last question, the subject was asked to subjectively assess their current thermal sensation on the continuous thermal sensation scale from EN15251 [9].



(1) (2) (3)

Fig. 1 Screenshots of the questionnaire questions:
For how long time have you been home? (1). What are you wearing? (2),
How do you perceive the temperature right now? (3)

3. Results

A total of 347 subjective votes were collected during the experiment corresponding to an average of four votes per day and approximately 17.5 votes per participant. The data was compared to the prevailing thermal comfort models, PMV, PMVe, and SCATs. Fig. 2 depicts the correlation between PMV and the corresponding thermal sensation vote (TSV) from the subjects. The TSVs are in general higher than the PMV values which suggests that the PMV model underestimates the subjective thermal sensation. This is opposite to findings from similar studies conducted for office buildings where PMV seems to overestimate the subjective thermal sensation [10].

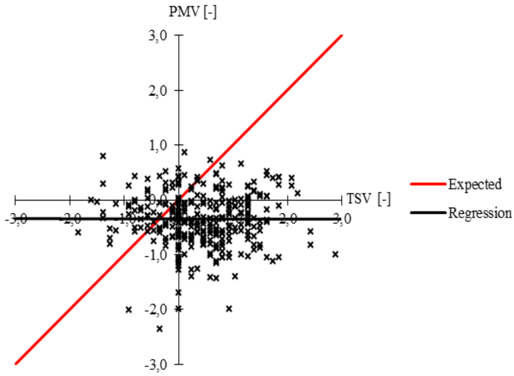


Fig. 2 Comparison of PMV and TSV

The reason for the deviations between PMV and TSV in Fig. 2 could be explained by the expectancy factor as defined by Fanger and Toftum [3]. The expectancy factor is therefore calculated as TSV divided by PMV. Provided that the self-reported clothing insulation is correct, Fig. 3 suggests an increased expectancy factor with lower clothing insulation indicating that the subjects have a high expectation to the thermal indoor conditions when they have low clothing insulation.

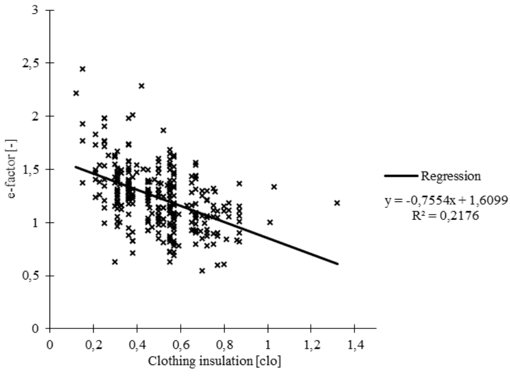


Fig. 3 Comparison of e-factor and clothing insulation

An analysis of the estimated input parameters in the PMV equation (metabolic rate and air velocity) was performed assuming correct air temperature, relative humidity and self-reported clothing insulation. In the analysis it was assumed that the PMV model always leads to a perfect prediction of the subjective thermal sensation. PMV was then approximated to the corresponding TSV by choosing the most favorable combination of metabolic rate within the range of 0.9 to 1.3 Met and air velocity within the range of 0.0 to 0.4 m/s. The result is depicted in Fig. 4. The tendency is still the same as in Fig. 2: PMV seems to underestimates the subjective thermal sensation. Furthermore, expectancy factors in the PMVe model generally still needs to be >1.

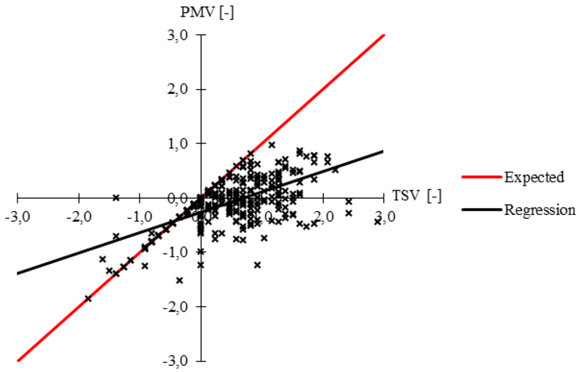


Fig. 4 PMV fitted to TSV by the changing the estimated air velocity and metabolic rate

To evaluate whether the adaptive SCATs model leads to a reasonable prediction of TSV in homes, the TSVs needs to be converted to a comfort temperature (t_c). The SCATs project [4] calculated t_c using the operative temperature but in this investigation we assume that the mean radiant temperature is equal to the room air temperature (t_i). t_c can thus be calculated as:

$$t_c = t_i - f \cdot TSV \qquad (1)$$

where f is a conversion factor. The conversion factor used in the SCATs project was f = 2 and is based on the Griffiths constant that describes the linear relationship between thermal sensation vote and operative temperature [11]. An alternative way of determining the conversion factor is to divide the 5 °C range of the cooling comfort interval for category C in EN15251 table A.3 [9] and divide it by 1.4 which is the span of PMV for class C (-0.7 to +0.7). This leads to a conversion factor of f = 3.6. Fig. 5 and Fig. 6 depict t_c as a function of the outdoor running mean temperature. Both figures contain a linear regression of the data together with the regressions found in the SCATs project. The figures suggest that the SCATs model could be used to predict thermal comfort in homes.

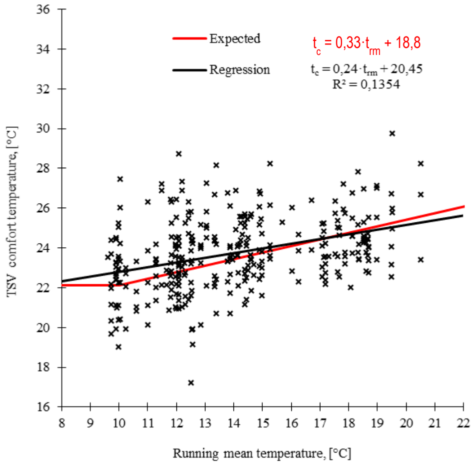


Fig. 5 Comparison of comfort temperature and running mean temperature, f=2

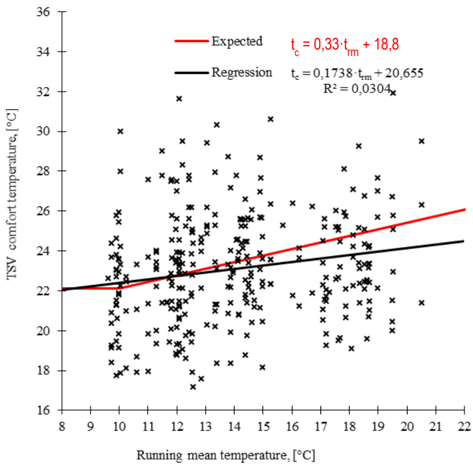


Fig. 6 Comparison of comfort temperature and running mean temperature, f=3.57

4. Conclusion

This paper reports on an investigation of prevailing thermal comfort models (PMV, PMVe and the SCATs model) in terms of their ability to predict thermal comfort in homes. The investigation was based on subjective thermal sensation votes over a period of three months summer period from 21 subjects living in single-room apartments at the Grundfos Dormitory in

Aarhus, Denmark. Objective measurements of room air temperature and relative humidity were also logged during the period.

The data suggested that the PMV model underestimates the subjective thermal sensation of the subjects. However, a number of parameters in the PMV model were estimated (not measured) and it can therefore not be ruled out based on this study that PMV or PMVe is not able to predict thermal comfort in homes. The SCATs model demonstrated a fairly accurate prediction of the subjective thermal sensation. However, the above conclusions are somewhat uncertain due to the limited sample size and lack of monitoring some parameters known to affect the notion of thermal comfort. As such, the investigation is a pilot study on how to gather and analyze data to investigate whether prevailing thermal comfort models are suitable to predict thermal comfort in homes – or whether they should be adjusted to fulfil this purpose.

Acknowledgment

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