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A Comparison of Calculated and Subjective Thermal Comfort Sensation in Home and Office Environment

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Abstract

This study was conducted to investigate the accuracy of the PMV model in residential buildings in UK and to find out whether a true "context effect" exists in explaining discrepancies between predicted and observed thermal sensation of occupants. Sixteen participants were subjected to a thermal comfort study at both their homes and office. Each subject voted on their thermal sensation while air and mean radiant temperature, air velocity and relative humidity were recorded. The comparison of reported thermal sensation and those predicted using ISO 7730 showed that in general PMV under predicts the thermal sensation of occupants in both environments. The neutral temperatures found in homes and offices were respectively 3ºC and 2.5ºC lower than those predicted using ISO 7730. Together with 0.2ºC difference found between reported neutral temperatures at homes and offices, this suggests that there is a true context effect affecting occupants' thermal sensation in different environments.

Keywords: Thermal comfort, PMV, Residential buildings, offices

1. Introduction

The predicted mean vote (PMV) equation proposed by Fanger in 1970 has been used in international standards to predict the thermal sensation of occupants since the 1980s (Parsons, 1993). It has been presented in international standards such as ISO 7730 and is probably the most broadly used thermal comfort index for designers to measure indoor thermal environments (Humphreys and Nicol, 2002). The PMV equation uses the four environmental parameters of air temperature, mean radiant temperature (MRT), air velocity and relative humidity (RH) and two personal variables of clothing insulation (Clo) and metabolic rate (Met) as inputs and predicts the thermal sensation of occupants on ASHRAE 7 points thermal sensation scale as showed below in Figure 1.

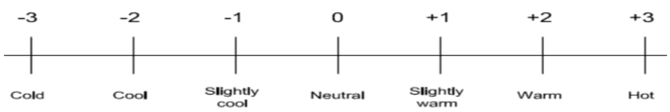

Figure 1: ASHRAE seven point thermal sensation scale

However, Fanger's model is based on theoretical analyses of human heat exchange by steady state laboratory experiments in Northern Europe and America. Therefore, since the development of the PMV equation, many field studies have been carried out worldwide to investigate its validity in the changeable, inconsistent environments of "real buildings" with "real occupants".

The PMV model has been validated by the majority of these studies as accurate predictor in air-conditioned buildings with HVAC systems in any climatic conditions (Fanger, 2002). However, in the case of naturally ventilated (NV) or non air-conditioned buildings, discrepancies have been observed between the occupants' thermal sensation and the expression of thermal comfort proposed by the PMV model. Humphrey (1976) and Auliciems (1981) reviewed 30 and 53 field studies respectively and both concluded that PMV generally underestimates thermal sensation and therefore overestimates the actual neutral temperature. Field studies in different climates and environments by Schiller (1990), Kahkonen (1991), Croome et al. (1992), Han et al. (2007) all confirm an underestimation of thermal sensation by the PMV model. Moreover, several studies have compared the reported neutral temperatures in different environments. Hun and Gidman (1982) found a considerably low operative temperature of 15.8ºC in a national survey in UK houses. A study by Pimbert and Fishman (1981) showed lower neutral temperatures in UK houses up to 2 ºC compared to offices and Cena et al (1986) also found a much lower neutral temperatures in houses (21.1 ºC) than offices (23.8 ºC) as reported in Brager and de Dear (1998). However, all these studies were based on different people living and working in different geographical locations.

Researcher such as Oseland (1995) stated that the PMV model is based on studying people in "artificial environments of climate chambers out of context with their usual environmental settings" and therefore attributed these discrepancies to what is called "contextual effects". Contextual factors are the non-physical parameters involved in perception of thermal comfort in different environments such as climatic settings, social conditioning and economic considerations (Brager and de Dear, 1998). Therefore, in order to investigate whether a true context effect exists in explaining the observed discrepancies, a more in depth study is needed. This study takes this approach by investigating thermal sensation of the same people doing same level of activity but in the different environments of homes and offices.

2. Methodology

Sixteen research students and staff of Loughborough University were invited to participate in this field study which was conducted in July 2011. All the participants were working in an open plan office shared with other colleagues at Loughborough University and living in naturally ventilated houses within a half hour travel from Loughborough University. Participants were consisted of six females and ten males from diverse ethnic origins and age groups.

Each subject took part in two experimental sessions; one at the living room of the subjects' house and one at the office. The experimental designs of both sessions were identical but conducted in the different environments of homes and offices. Subjective measurements, in form of a thermal comfort questionnaire and objective measurements were taken during each survey. Each session lasted 2 hours and during each session the participant was asked to sit down in the office or in the living room doing sedentary works or relax. In order to control the metabolic rate, the participants were asked to feel free to do sedentary activities such as reading, chatting but were not required to stand up, walk, play computer games, watch television or eat and drink. The main survey was conducted in the last 45 minutes of each 2 hours session in which participants rated their thermal sensation (Actual Mean Vote (AMV)) on the ASHRAE seven points scale every 15 minutes by means of a questionnaire. Therefore 4 sets of survey responses were obtained from each participant. For 16 subjects, this procedure resulted in a total of 128 survey responses, i.e. 64 survey responses for offices and 64 for living rooms. Figure 2 briefly indicates the experimental design of each 2 hours session.

Figure 2: Experimental design during each session

Metabolic rate of the subjects required in PMV equation were estimated according to Table B.1 in ISO7730 (2005) based on their activity level. Participants were asked to calculate their own total thermal insulation of clothing by adding the corresponding insulation values of the clothes they were worn at the time of completing the survey. Both males and females had their individual clothing list which was a simplified version of that provided by Table C2, ISO 7730 (2005). All the total clothing insulation values calculated by the subjects were added by 0.1 Clo to consider the thermal insulation of the chair or sofa of the participants. Mean radiant temperature (MRT), relative humidity (RH), air velocity (V) and air temperature (T) (the environmental parameters required to calculate PMV) were recorded using a multi functional measuring instrument called Testo 400. All the were taken by probes set up (at abdominal level for the seated participants at the height of 60 cm and 30 cm away from the participants) and recorded at 15 minutes intervals which coincide with the time the participants completed the questionnaire. Measured environmental parameters along with the estimated metabolic rate and clothing insulation were inserted in a spreadsheet based on the algorithm provided in ISO 7730 to compute PMVs.

3. Results and Discussion

Figure 1 and 2 indicate the calculated PMV and reported AMV for each participant in this field study at their homes and offices respectively. The PMVs and AMVs used to plot these diagrams are the mean values of 4 PMVs calculated for each subject per environment and 4 AMVs reported by occupants.

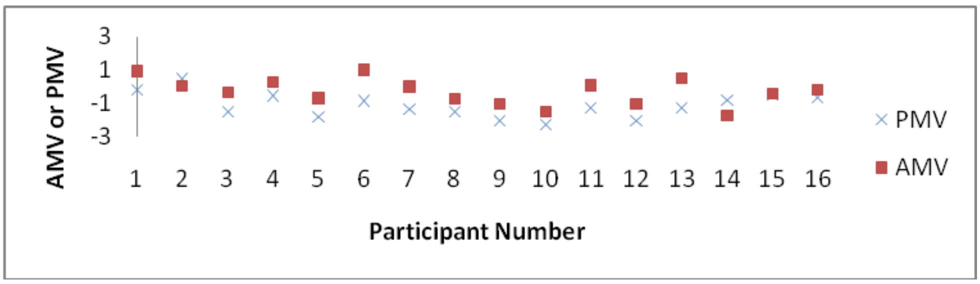

Figure 1: Mean PMV calculated and AMV reported at each house for 16 participants

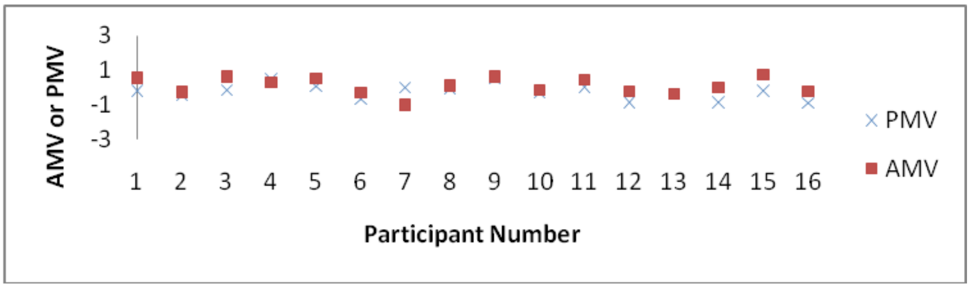

Figure 2: Mean PMV calculated and AMV reported at each office for 16 participants

As can be seen in both environments Fanger's PMV model generally under predicts the thermal sensation reported by occupants (AMV).

PMV computed according to Fanger's model have been plotted versus operative temperature in homes and offices by Figure 3 and 4 respectively. These figures reflect the differences between PMV and AMV in neutral temperatures.

The linear regression equations that best fit the survey data at homes are:
$AMV = 0.2893\ T_0 - 6.7738\ (R^2 = 0.3902)$ (Equation 1) and
$PMV = 0.2801\ T_0 - 7.406\ (R^2 = 0.4431)$ (Equation 2) where T_0 (° C) is the operative temperature. The neutrality value for homes is estimated by solving Equation (1) for AMV equal to zero denoting a comfortable thermal environment. The neutral operative temperature at homes found 23.4ºC. Similarly the predicted neutral operative temperature by PMV model is found by solving Equation (2) for PMV equal to zero. The predicted neutral operative temperature at homes by PMV model is 26.4ºC which is 3ºC higher than the actual neutral operative temperature found at homes. In addition, linear regression equations that best fit the survey data at offices in Figure 4 are: $AMV = 0.1587\ T_0 - 3.6883\ (R^2 = 0.0662)$ (Equation 3) and
$PMV = 0.1249\ T_0 - 3.2196\ (R^2 = 0.0539)$ (Equation 4).

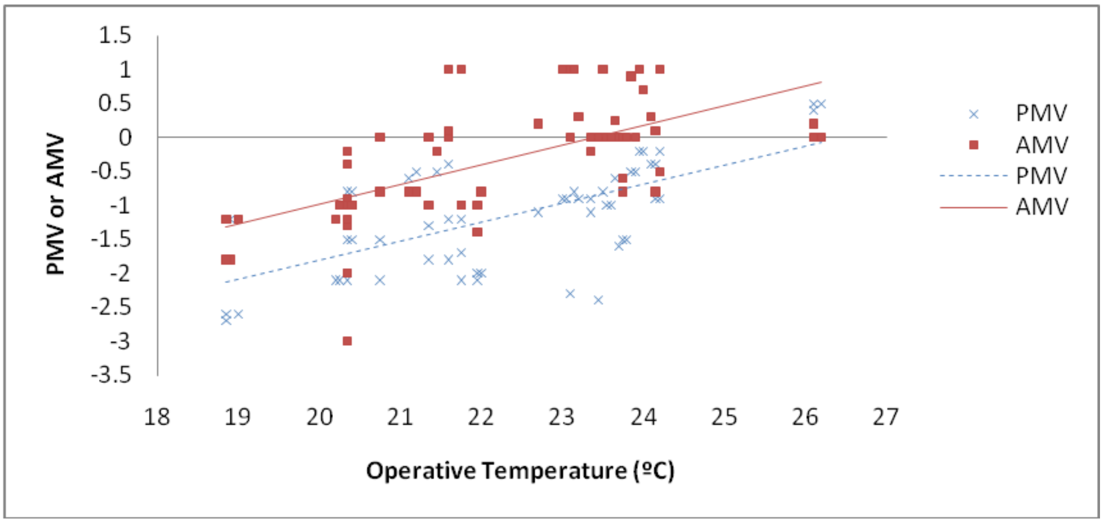

Figure 3: PMV and AMV by operative temperature (T_0) in homes

The predicted neutral operative temperature at offices by PMV model (from Equation 4) is 25.7ºC which is 2.5ºC higher than the actual neutral operative temperature (23.2 ºC) (from Equation 3) found at offices.

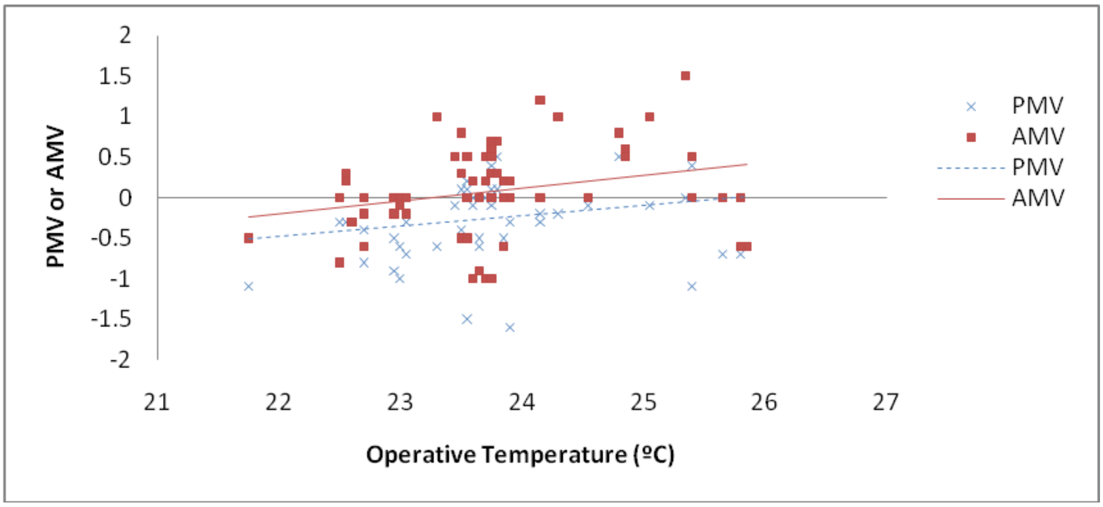

Figure 4: PMV and AMV by operative temperature (T_o) in offices

In summary, the PMV predicted a higher neutral temperature compared to the actual thermal sensation of occupants (AMV) in both environments of homes and offices. This result is in agreement with studies by Schiller (1990) and Croome et al. (1992) for a number of offices and Oseland (1995) in a sample of owner occupied homes which have found that the PMV generally estimated the thermal sensation lower than the actual thermal sensation in both homes and offices and therefore over predict the neutral operative temperatures. The difference between predicted and actual neutral operative temperatures found by Schiller (1990) and Croome et al. (1992) at offices was 2.4ºC, in very close agreement with the difference of 2.5ºC calculated in this study. The difference between predicted and actual neutral operative temperatures found in homes by Oseland (1995) up to 5.4ºC while this study found a lower difference of 3ºC.

Moreover, independent of the relationship between AMV and PMV, analysis above showed that there is a difference of 0.2 ºC between the neutral temperatures found from reported thermal sensations (calculated from Equations 1 and 3) of the same people at different contexts of homes and offices. Even if the estimation of metabolic rate and clothing insulation were inaccurate, this may show that there is a true context effect on thermal sensation explaining the difference between the reported neutral temperatures found in different environments. However, the difference found in this study (0.2 ºC) is small, and further larger scale studies are needed to confirm the findings in this study.

4. Conclusions

This research was mainly aimed to investigate the accuracy of PMV model in predicting thermal sensation of the occupants in naturally ventilated houses and offices and to determine whether or not a true context effect exists in explaining the differences between thermal sensations of the occupants in different environments. The study showed that Fangers' PMV model generally under predicts the thermal sensation reported by occupants (AMV) and thus PMV can only partially predict thermal sensation in naturally ventilated offices and homes in UK. In addition, it was found the PMV predicts a higher neutral temperature compared to the actual thermal sensation of occupants in both naturally ventilated homes and offices in UK. This is in line with the majority of the more recent studies including several geographic locations and therefore climatic conditions and various types of buildings which show that PMV index under predict the actual thermal comfort conditions and consequently predict higher neutral temperatures. Moreover, a difference of 0.2 ºC found between the actual neutral temperatures of the same people at different contexts of homes and offices (23.4 ºC and 23.2 ºC respectively) could suggest existence of context effects affecting thermal sensation of occupants in different environments. However, the difference is fairly small and further similar but larger scale studies is needed in order to confirm the applicability of the findings in this study. It is anticipated that the findings from this study will have energy implications since the study suggests different comfort conditions than predicted by ISO7730. In addition, it will help the organizations such as ASHRAE to provide a larger database of field studies in the case of residential buildings in order to validate the accuracy of the PMV model in UK houses.

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