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How to test Fanger's PMV model in a field study?

Mohammad Kotbi, Steve King and Deo Prasad

Faculty of the Built Environment
University of New South Wales
Sydney, NSW, Australia
Email: z3108183@zmail.unsw.edu.au

Abstract

Fanger's predicted mean vote (PMV) model of thermal comfort performance is the most commonly adopted in academic researches. But Fanger's model has been criticised in much of the same work, particularly with reference to the consistency of the results of applying the model in field studies.

Given that the PMV model is based on studies in controlled environment chambers, the applicability of the model in a real field study is arguably impossible, because it would assume that the indoor space is climatically controlled, the occupants practice the same level of activity with similar clothing, and without any consideration to the adaptability of the occupants.

An ongoing study regarding thermal comfort of a particular building typology, has proposed an answer to this dilemma. The paper discusses suggested methods for a field study that could meet all the circumstances that the PMV model assumes, and provide the basis for validating the model.

Keywords

Thermal comfort, PMV, Validating, Field studies, Mosques.

Introduction

By applying PMV model on an indoor environment, it predicts the average comfort vote of a group of occupants on the ASHRAE scale of thermal sensation and by further calculation the percentage of people dissatisfied regarding thermal environment. The model uses inputs of four environmental variables, air temperature, mean radiant temperature, air velocity and humidity, with two personal variables, metabolic rate and the insulation of the clothing (Fanger, 1970).

There are strong arguments that the PMV model is not applicable in free running indoor conditions (Humphreys, 1978; de Dear and Auliciems, 1985; Brager and de Dear, 1998). It is usually noted that the PMV needs a steady state condition, it is not sensitive enough for fluctuating environmental conditions, and it does not take into consideration the adaptability of the occupants to improve their thermal comfort, to some extent, if needed (de Dear and Brager, 2001).

In buildings, when applying the PMV model on naturally ventilated indoor spaces, it seems to overestimate the thermal sensation of the actual mean vote of the occupants (Humphreys, 1978; Brager and de Dear, 1998). That makes the model inapplicable on free running buildings, because the model does not consider some affecting factors such as the expectations and thermal preferences (de Dear and Brager, 2002; Fanger

and Toftum, 2002). Therefore, there is no need for validating the model on naturally ventilated spaces. On the other hand, since the model uses four environmental variables as inputs, it needs to be tested on an environment with steady state conditions, which is rarely occurring in real field. The model needs to be applied on a single space that is controlled environmentally to be correctly validated as it is originally developed. Thirdly, the metabolic rate of the occupants is generalised as one input for all the occupants, again hardly likely to occur in a real occupied space (Goto et al., 2006), more especially if applied regardless of the proportion of the male and female subjects even though they have different metabolism. In some cases, even if the occupants are governed by a uniform, the clothing insulation variable is also generalised regardless of the differences in gender. Moreover, the adaptability factor is an important criterion that affects the outputs of the model when applied in a real field setting, because the adaptability is a psychological issue that could not be prevented nor estimated.

Humphreys was one of the first to deeply question the validity of PMV model in every-day normal life (Humphreys and Nicol, 2002). According to Humphreys, "*PMV predicts the mean comfort vote of a large group of people exposed to the same thermal environment, wearing clothes having the same level of insulation, and all having the same level of activity. This circumstance rarely, if ever, occurs in practice... How then can PMV be tested against these data?*" (Humphreys and Nicol, 2002, p.669). This argument is still not answered. However, this paper is aiming to provide a proposed field study that could overcome the difficulties.

Mosques

The mosque is the place of worship for Muslims; congregational prayers are performed in mosques. The basic mosque contains two main spaces; the prayer hall and the ablution area. The prayer hall in a basic mosque is a simple rectangular shape single story, with carpet floor and no furniture (Numan, Al-Shaibani and Al-Maziad, 1999). In the mosque, five obligatory prayers are performed daily; the average prayer lasts from around fifteen to twenty minutes (Al-homoud, 1999; Abdou, Al-homoud and Budaiwi, 2005). When performing a congregational prayer, Muslims are guided by a leader called 'Imam'. Therefore, for all intents the activities of all the participants are synchronised, and may be considered to be the same. The performance of prayer consists of reciting words and performing movements including postures such as standing, bowing and sitting. The prophet Mohammed, peace be upon him, said "*Offer your Salat (Prayer) the way you see me offering them*" (Al-Bukhary). Therefore, within accepted Muslim practice, any intentional action or movement departing from the actual performance of the prayer is not allowed and would make a person's prayer invalid or unaccepted by God.

Some characteristics regarding the function of Mosques which are related to the focus of the argument are highlighted above. However, Riyadh, Saudi Arabia, has further criteria that help to fulfil the basics of the argument. First of all, air-conditioning is not a luxury in Riyadh; it is more a common practice. Dusty atmosphere, affordable low price energy and extremely hot climate are the most obvious reasons for this trend (Kotbi, King and Prasad, 2008). The case of mosques is not an exception. As public buildings, all mosques in Riyadh are air-conditioned. On the other hand, in Saudi Arabia, participation in congregational prayer in mosques is very common. With some exceptions, all the mosques are normally occupied by males only, because

females are highly encouraged to pray in their home, especially the five obligatory prayers.

The last important criterion is that in Saudi Arabia, especially in Riyadh, the male citizens, regularly wear the national costume of Saudi Arabia in every circumstance, including attending mosques. The figure shows a mosque in Riyadh during a prayer, illustrating the large percentage of similarity in the clothing ensembles. It also reveals the state of mental concentration while praying. Because of the hot climate, the national costume of Saudi Arabia is always made of white light fabric, the head cover is light fabric, in white or white/red color. Foot wear is not allowed inside the mosques; therefore, all the occupants are bare-foot while praying.



King Khalid Mosque in Alshafa, Riyadh

The case

It is clear that the Mosque as building typology, particularly in Riyadh, has the properties that could overcome the difficulties that have been identified for validating the PMV model in a real field study, it could meet all the circumstances that the PMV model assumes.

There are several factors that make the simple air-conditioned mosque a steady state condition environment:

- it has one single space that is occupied in several intermittent durations;
- each lasts around fifteen to twenty minutes;
- the functional areas for the measurement of the environmental variables are easily addressed with fixed height and place, as all the occupants have the exact postures in the same place.

That makes the measurements of the four variables very consistent regarding the place, height and time of measurements.

The personal variables in mosques in Riyadh are also very consistent. As the mosque would have only male occupants, the metabolic rate of one occupant may be applied as the general metabolic rate of all the occupants, because the activities and the movements of the occupants during a prayer are exactly the same, as well as their gender. Furthermore, clothing ensembles are also very similar between all the occupants of the males only mosques in Riyadh, making the calculation of the clothing insulation safely generalised for all the occupants.

The methods

In a future stage of the ongoing study, the personal variables are to be determined in advance. Ideally, the average metabolic rate of a group of praying subjects from the same ethnic background of Saudi Arabian citizens, maybe calculated in laboratory. Alternative methods are comparing heart rate during praying and sedentary activity, or calculating the oxygen consumption. Further analysis of the appropriate method is to be undertaken. The second personal variable, clothing insulation, should be calculated using thermal manikin. Two key clo values should be derived, one clo for the Saudi national costume with head covering and one of the same ensemble without the head cover.

After the preliminaries, the research would take place in selected mosques in Riyadh, Saudi Arabia during the summer season, to insure that the mosques are air-conditioned, as well as insuring that the occupants are wearing clothing with similar insulation.

The PMV model would be applied to the steady state environment of the mosque during the latter part of the functional period, i.e. prayers time. It is proposed to measure the four environmental variables at the height of one metre at several points in the centre of each mosque during a prayer, using appropriate standalone data loggers. The height of one metre should be reasonable for both postures of standing and sitting (Al-homoud, Abdou and Budaiwi, 2009). The loggers are to be attached to the walls and the columns of each mosque in such a manner as to be reasonably certain that they are likely to be subject of the space's variability for local air movement in response to register placement of the air conditioning, or variations in radiant asymmetry. Only if previously established as necessary, the mean radiant temperature is to be approximated from the combination of unshielded globe temperature and DBT. Otherwise, at least during some prayer periods in each of the subject mosques, the radiant environment is to be surveyed by use of an infra-red thermometer, to verify that the majority of surface temperatures are within less than 2°C of DBT.

Each prayer has to last for more than fifteen minutes to be valid for the application of the model, because less than fifteen minutes is insufficient time to reach an appropriate metabolic steady state (Goto et al, 2006).

Finally, in each mosque, a short questionnaire survey is to be administered to the occupants just after the prayer is finished. The scope of the survey questionnaire is proposed to be limited to record vote on the ASRAE scale of subjective warmth and the comfort scale. The questionnaire will also ask if the subject is/was wearing a head cover or not, to classify the relevant clo value. The results of survey questionnaires are proposed to be treated statistically to establish one or more approximations of the actual mean vote.

Conclusion

In short, a broader ongoing research project examining thermal comfort in mosques in Riyadh, Saudi Arabia, has provided a unusually well formed vehicle to validate the PMV model in a real field study. Comparing the results of the predicted mean vote (established by monitoring the relevant environmental variables and applying by calculation the result of the application of PMV model), and the actual mean vote(s)

of this real field study would be the most appropriate basis for the validation of the PMV model, and should be the answer to Humphrey's question.

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