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Thermal comfort assessment of large-scale hospitals in tropical climates: A case study of University Kebangsaan Malaysia Medical Centre (UKMMC)

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ABSTRACT

A field study on thermal comfort assessment was carried out in a large-scale hospital in a tropical climate. To evaluate thermal comfort, both subjective and objective measurements were performed. The data were collected from 10 various thermal zones of a hospital. In each zone the predicted mean vote (PMV) was calculated based on the Fanger theory. In addition, the thermal sensation vote (TSV) was calculated according to the survey to find the relationship between the Fanger model (PMV) and the occupants' votes. In this study a strong relationship between PMV and TSV was found when $R^2 = 0.88$. According to this correlation the neutrality point shifted to +0.7 on the seven-point ASHRAE scale. Moreover, the neutral effective temperature (ET*) was calculated based on the TSV and PMV of 23.4 °C and 21.3 °C, respectively, indicative of compatibility with the adaptive theory. The results also demonstrate that the preferred effective temperature according to subjective assessment in this case study is 20.2 °C. This analysis revealed that to the respondents of this study in 10 thermal zones the neutral temperature point is higher than global standards, while the preferred temperature is lower than standards and the neutrality point.

1. Introduction

Thermal comfort guidelines are necessary to assist and guide building designers provide adequate indoor climates [1]. Proper indoor thermal conditions in buildings are important not only because the building occupants will be comfortable, but also because building energy consumption as well as its sustainability will be affected [1]. According to studies, a building with thermal comfort may increase the workers' performance and productivity and decrease the absenteeism rate [2]. The thermal comfort requirement in hospitals is particularly vital as patients are more sensitive to environmental factors than healthy people due to their fragile conditions and illnesses [3]. Prior studies have found that a suitable indoor air climate can shorten the patients' length of stay at the hospital [4].

Two parameter types that influence thermal perception are environmental and personal factors. The main environmental factors include air temperature, mean radiant temperature, relative humidity and air velocity, while the main personal factors consist of clothing insulation value and metabolic rate. These factors were researched in the 1970s and have lead to the development of thermal comfort standards and guidelines of the ASHRAE standard 55 [5]. Studies were carried out at Kansas State University by Ole Fanger and others who identified comfort perception as a complex interaction between various personal and environmental factors. Moreover, their findings showed a maximum number of satisfied people in a specified set of values. With the deviation of a value set, the percentage of satisfied people decreases. The two main thermal comfort indexes introduced are PMV (predicted mean vote) and PPD (predicted percent of dissatisfied people). PMV represents the predicted mean vote of people exposed to a certain environment with the votes based on the thermal sensation scale (Table 1). In addition, PPD represents the percentage of unsatisfied people at each PMV. Table 1 illustrates the seven-point thermal sensation scale. PMV sets up a thermal strain based on steady-state heat transfer between the human body and environment, and it specifies a vote to that amount of thermal strain. As the PMV deviates from zero which represents a neutral condition on either the positive or negative side, PPD increases.

The PMV model is a steady-state model which only applies to people exposed to a constant condition and activity rate for an extended time. To date, PMV is the most widely used thermal comfort index. ISO (International Standard Organization) Standard 7730 [6] employs PMV limits as an express comfort zone classification.

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Table 1
The seven-point thermal sensation scale.

No.	Definition	Numerical value
1	Cold	−3
2	Cool	−2
3	Slightly cool	−1
4	Neutral	0
5	Slightly warm	+1
6	Warm	+2
7	Hot	+3

Fanger and co-workers studied the difference between various subject groups from tropical and non-tropical regions as they likely adapt to heat differently. Their findings in Denmark showed no major difference among subjects from various regions [7]. Later studies by de Dear et al. performed in tropical Singapore, were in agreement with these findings [8]. Nevertheless, consequent works have not always produced similar results [7], as revealed by Webb [9], Nicol and Humphreys [10], Busch [11], Nicol et al. [12], Taki et al. [13], Bouden and Ghrab [14], Humphreys [15] and de Dear and Brager [16]. These studies investigated the subjects' perception in familiar thermal situations. According to the studies, the condition in which the respondents felt neutral (vote = 0 on the seven-point scale) was different from the ASHRAE and ISO7730 predictions. Particularly in a free running building the prediction power of the standards had low accuracy. The standards were overestimated at high temperatures and underestimated at low temperatures (cold climate) [7]. Nicol and Humphreys [10] showed that the mean comfort vote of the respondents changed slightly with the mean temperature experienced. Subsequent studies conducted by Humphreys [15] confirmed that the comfort temperature is closely related to the mean temperature people experienced either in a cold or hot climate due to adaptation and acclimatization.

People tend to adapt naturally to the changing surrounding environment. This tendency has been explained in the adaptive theory of thermal comfort [1]. In other words, people find ways to make themselves comfortable with their normally experienced condition, meaning they adapt behaviourally [7]. The basis of the adaptive approach is that people consciously or unconsciously play an active role in creating a comfortable condition and do not suffer passively from environmental conditions [17]. The adaptive approach is more suitable in NV (naturally ventilated) buildings where the occupants have better chances of changing and modifying their surroundings [17].

Humphreys found a linear relationship between mean outdoor temperature and comfort temperature for NV buildings [7].

$$T_c = 0.534T_o + 12.9 \qquad (1)$$

where T_c is the comfort temperature and To is the mean outdoor temperature.

Other studies give evidence that the adaptive theory is not only applicable to NV buildings, but may also concern air-conditioned buildings. Yau and Chew [18] demonstrated in a study they carried out in a Malaysian air-conditioned hospital that there is a deviation between the occupants' vote (TSV) and predicted vote (PMV). It implies that applying the PMV model might not be suitable for tropical hospitals and occupants would be more satisfied with higher temperatures. Examples of other research works done in hot and humid areas which found that occupants accept the thermal environment but failed to meet the standard comfort criteria are by Kwok [19], Karyono [20], Kwok and Chu [21] and Azizpour et al. [22].

This paper will evaluate the thermal comfort in a tropical, large-scale hospital and examine the standard criteria. The objectives of this research are as follows:

Fig. 1. General view of the case study building (UKMMC).

- To evaluate thermal comfort in different hospital thermal zones.
- To find the new neutral point on the 7-point ASHRAE scale, the new PMV* based on the correlation between TSV and PMV.
- To find the neutral effective temperature (ET*) and new limit for 80% satisfaction in hot–humid regions based on TSV and PMV.
- To identify the preferred temperature (ET*, OT) based on TPV (thermal preference vote).

2. Methodology

2.1. Site description and climatic background

This study was carried out in one of Malaysia's teaching hospitals. Malaysia is located in a tropical region in Southeast Asia. Its geographical coordinates are 2°30′ north latitude and 112°30′ east longitude [23]. Being near the equator, Malaysia experiences a hot and humid climate, with constant high temperatures and relative humidity throughout the year. UKMMC (University Kebangsaan Malaysia Medical Centre) is the hospital selected for this case study, with a 240,000 m^2 built-up area including three blocks: clinical, educational and residential blocks [24]. Fig. 1 illustrates the general view of UKMMC via Google Earth.

2.2. Objective measurements

"Thermal Comfort" was the equipment used for measuring and recording the environmental factors in this work, including ambient temperature (T_a), globe temperature (T_g), relative humidity (RH%), air velocity (V), light level (LUX), noise and CO_2 [25]. Fig. 2 demonstrates the apparatus employed. The equipment was set at 1.1 m above the floor. To evaluate the case study's thermal

Fig. 2. "Thermal Comfort" equipment.