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Physiological and subjective thermal response from Indians

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ABSTRACT

A controlled laboratory experiment was carried out on forty Indian male college students for evaluating the effect of indoor thermal environment on occupants' response and thermal comfort. During experiment, indoor temperature varied from 21 °C to 33 °C, and the variables like relative humidity, airflow, air temperature and radiant temperature were recorded along with skin (T_{sk}) and oral temperature (T_{core}) from the subjects. From T_{sk} and T_c, body temperature (T_b) was evaluated. Subjective Thermal Sensation Vote (TSV) was recorded using ASHRAE 7-point scale. In PMV model, Fanger's T_{sk} equation was used to accommodate adaptive response. Stepwise regression analysis result showed T_b was better predictor of TSV than T_{sk} and T_{core}. Regional skin temperature response, lower sweat threshold temperature with no dipping sweat and higher cutaneous sweating threshold temperature were observed as thermal adaptive responses. Using PMV model, thermal comfort zone was evaluated as (22.46–25.41) °C with neutral temperature of 23.91 °C, whereas using TSV response, wider comfort zone was estimated as (23.25–26.32) °C with neutral temperature at 24.83 °C. It was observed that PMV-model overestimated the actual thermal response. Interestingly, these subjects were found to be less sensitive to hot but more sensitive to cold. A new TSV-PPD relation (PPD_{new}) was obtained with an asymmetric distribution of hot-cold thermal sensation response in Indians.

1. Introduction

A healthy and comfortable thermal environment of indoor workspace makes the occupants comfortable with improved work efficiencies and well-being. Thermal sensation refers to subjective thermal perception as how the person feels the environment – warm, neutral, cold etc. Different environmental parameters, activity level and clothing worn by the occupants affect thermal sensation experienced by a person. The word "thermal comfort" is defined by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), as the condition of mind which expresses human satisfaction with the thermal environment [1,2]. To evaluate subjective thermal sensation, International standards such as ISO 7730 (2005) [3] and the ASHRAE Standard 55-92 [2] describes a method to estimate subjective thermal sensation based on Predicted Mean Vote (PMV) model, developed by Fanger [4]. Otherwise, researcher often ask the subject to rate their response using 7-points ASHRAE voting scale that covers a range of cool (−3) to warm (+3) sensation and to discriminate the result from calculated PMV response, it is generally named as Thermal Sensation Vote (TSV) or Actual Mean Vote (AMV). From this subjective response, thermally comfortable condition (all votes between +1 (slightly cool) to +1 (slightly warm)) is evaluated.

Fanger's PMV model calculates subjective response to the thermal environment directly from environmental parameters as it assumes that thermal sensation experienced by a person, a passive response which is a function of physiological strain imposed on him by the environment, and it does not clarify how people respond physiologically and subjectively to the thermal environment. Many researchers are beginning to challenge this concept as they claim that the adaptation (psychological, behavioral, cultural and clothing adaptation) is region specific, which influences person's thermal preference beyond mere passive experience of a body's thermal balance and highly influenced by the local climate conditions and socio-cultural set-up, so it may be impossible to assign a specific value to thermal comfort standard [5–7]. In ASHRAE RP 884, "adaptive PMV" is mentioned to include occupant's adaptive response especially in case of occupants in the naturally ventilated buildings [8]. Several authors have reported that especially the people living in the tropical regions, having higher optimum temperature than those in the cold regions due to the adaptation [9–14]. Hwang et al. have conducted field experiments in 10

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naturally ventilated and 26 air-conditioned campus classrooms in Taiwan, and found that occupants who have acclimated to the hot-humid climate can accept warmer thermal environments [15].

India is having tropical climate with large variation in environmental conditions in different regions [16]. Different inhabited environmental condition produces different subject sensations due to level of adaptation in climatic condition, living patterns, eating habits etc. as reported in case of Indians [17]. Sharma and Ali have assessed thermal sensation for Indians and developed “Tropical Summer Index (TSI)” and identified Indian thermal sensations as “slightly cool”, “comfortable” and “slightly warm” at 19–25 °C (with optimum at 22 °C), 25–30 °C (with optimum at 27.5 °C) and 30–34 °C (with optimum at 32 °C) respectively [17]. Our neighboring country Bangladesh is also having similar type of environmental conditions. Air temperature range of 24–32 °C with relative humidity ranging between 50 and 90% and without or in little air movement is reported as thermal comfort zone for Bangladeshi people [18]. Indraganthi has estimated the comfort band for Indians to be (26–32.45) °C with the neutral temperature at 29.23 °C [19] from field study. However, the National Building Code of India (BIS, 2005) advocates the use of two indoor temperature ranges for summer (23–26) °C and winter (21–23) °C for all the climatic zones, which is similar to ASHRAE recommendation but far above than the earlier reported results [20]. For better prediction of thermal response in Indians, it is required to quantify human perception of different thermal conditions and how it is correlated with the physiological parameters.

Actually, thermal response is initiated by behavioral thermoregulation, where both mean skin-surface (T_{sk}) and core (T_{core}) temperatures are known afferent inputs to the thermoregulatory system, and contribute about equally toward determining thermal comfort [21]. Hence, both skin and core temperatures are potential physiological parameters for objective evaluation of human thermal sensation experienced by the surrounding environment. Skin temperature initiates thermoregulatory response before activating stronger autonomic and metabolic responses controlled by core temperature to maintain the body temperature. However, estimation of T_{sk} is relatively easy, while measuring T_{core} is always challenging. Rectal temperature is regarded as the most valid core temperature index but it is impractical, invasive and expensive for everyday clinical use. Therefore, oral temperature (recording from sublingual pocket) is one of the common index for T_{core} as it's measurements are easy and reliable. No literature is available on thermal response studies in Indian climate on their natives, and researchers have concluded for the requirement of further study.

In this context, a laboratory study is conducted to investigate how mean skin temperature, oral temperature and body temperature are correlated with TSV responses at different thermal environments and any adaptive variations in objective measurement. A new relation is aimed to establish on TSV and the number of responder at different air temperatures, similar to Predicted Percentage of Dissatisfaction (PPD) in PMV model to highlight the thermal adaptive response of Indians. This study also aims to evaluate indoor thermal comfort condition for Indians from this TSV-PPD response, and compare the result with PMV-PPD model estimated result.

2. Methodology

2.1. Subjects

Forty young male university students having age – (25.18 ± 2.4) years, weight – (68.6 ± 8.46) kg and height – (1.71 ± 0.05) m participated in this study as volunteers. They were originally from different part of the country and none of them were professional athletes. The Body Mass Index (BMI) was calculated as ratio of body weight (kg) and square of body height (m) and obtained as 23.38 ± 2.03. Body Surface Area (BSA) of individual participant was calculated using DuBois and DuBois [22] equation, used to normalize the heat flow parameters.

Prior to the participation, subjects were informed in details about the experiment and their consents were collected. To have uniform effect of local climatic acclimatization, no subject was selected as a new comer to this environment. All these subjects spent at least one year in this university campus. Subjects were instructed not to consume alcohol or medical drugs within 48 h before testing and not to have any food (except water) for at least two hours before the experiment and no water intake during the experiment. They were not suffering from any chronic illness. After arrival, the subjects took 15–30 min rest in sitting posture prior to start the experiment with a normal room temperature of around 26 °C. They were not prior exposed to heavy physical work. Then they were asked to put-on the experimental clothing: a half sleeve cotton shirt with their inner garments and a white cotton cloth, called dhoti, was double folded and plain wrapped around the waist to record the skin temperature easily with no active air movement in microenvironment area. They were bare feet during the experiment. The clothing insulation value (I_{cl}) was estimated as 0.47 clo, where 0.04 clo: men's briefs, 0.19 clo: half sleeved shirt, 0.24 clo: double folded dhoti.

2.2. Measurement of ambient parameters

Experiment was conducted in the month of February and March at Bangalore. During that period, the average outdoor climate temperature was (26.4 ± 3.9) °C (ranging from average daily minimum of 19.9 °C and maximum of 32.8 °C) and the average relative humidity was 46.95 ± 18.8% and inside our campus the outdoor temperature was (18–32.0) °C with average of 25 °C. Bangalore is having moderate climatic conditions throughout the year with average ambient temperature 33.5 °C; solar radiation, 507 W m^{-2}; wind velocity, 4.9 m s^{-1} [16]. In present study, indoor ambient temperature was varying from 21 to 33 °C with an interval of 1 °C except between 22 °C and 21 °C, it was 0.5 °C. The whole experiment was conducted in two phases with a gap of at-least half a day to normalize their thermal response. First phase was conducted inside a conference room (Room A), where the ambient temperature was varied from 27 °C to 21 °C with gradual lowering the room temperature. The room ambient temperature was controlled by an air conditioner (LP-K3685QC – floor stand type AC, Capacity: 3.0 Ton, manufactured by LG Electronics) with an outlet (dimension of 0.55 m × 0.32 m × 1.8 m) situated at 1.6 m height, placed inside a conference room (2.5 m × 5 m × 3 m). The airflow rate of the cooler was 1054 m^3/h. The minimum set temperature of the cooler was 16 °C. This room was having insulated walls, false ceiling and PVC flooring. As, it was very difficult to increase the temperature beyond 27 °C using air conditioner, therefore, the study of higher ambient temperature was conducted inside another laboratory room having almost same size (Room B), where the room temperature was adjusted between (28–33) °C in ascending fashion using one heating oven (model UNP 700, memmert) with heating area of 1040 mm × 800 mm × 500 mm, and two coil type cooking heaters (1000 W) and one pedestal fan not facing directly towards the subject (Fig. 1). When the room ambient temperature reached to the set level, the oven and heaters were switched off and covered with a cloth to avoid the radiation from them and the fan was switched off temporarily and then the measurements were taken. Instead of using psychometric chamber, present study was conducted in a familiar natural environment as a general workplace for the subjects using auxiliary devices, where they could feel free and participate without being inside the enclosed chamber. Changing the ambient temperature from one level to the next usually took around 5 min, but 10 min was allotted and during this time subject relaxed in sitting. Then,