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Preferred temperature with standing and treadmill workstations

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ABSTRACT

Prolonged sedentary behavior has been shown to increase chronic diseases. Using standing and treadmill desk reduces sitting time, increases metabolic rate and thus has potential to improve health. There is little existing guidance on how to keep thermal comfort when using standing and treadmill desk. It is unknown what are the suitable ambient temperatures for occupants at elevated office activity levels. This experiment investigated thermal sensation and preferred temperature at elevated office activity levels, including sitting (SED), standing (STD), and two slow-walk speeds: walking at 1.2 km/h (TRD1) and walking at 2.4 km/h (TRD2). Comfort votes were obtained from 20 subjects under personal controlled ambient temperature. The active workstation significantly increased human metabolic level and reduced preferred temperature. The measured metabolic rates were 1.0, 1.1, 1.9 and 2.5 met for SED, STD, TRD 1 and TRD 2. The preferred ambient temperature reduced from 25.85 °C for SED, to 25.0, 24.1 and 23.2 °C for STD, TRD 1 and TRD 2 respectively. All subjects were comfortable at their preferred temperatures. PMV model was found to predict too cool temperature than needed for higher metabolic rates.

1. Introduction

Prolonged sedentary behavior, which is pervasive in contemporary occupational tasks, was confirmed to be significantly associated with an elevated risk of chronic diseases [1]. Since sedentary behavior was first highlighted as a risk factor to health in the 1950s [2], there have been extensive studies to determine the relationship between sitting time and health effect. Recent evidence showed that the extend periods of sitting affects health outcomes, even in individuals who are otherwise physically active. For example, several studies demonstrated that sitting time was associated with an elevated risk of all-cause and cardiovascular disease mortality, but was independent of other physical activity [3] [4]. More specially, increasing sitting time is strongly associated with rates of metabolic syndrome, type-2 diabetes mellitus, and obesity [4].

Office occupants were identified as a majority of current sedentary behavior that spent the day sitting. Therefore, workplace is a key setting to introduce strategies to reduce sitting time and increase break up periods to improve health [5] [6]. Recently, workstations wherein the user stands or walks using a specially designed "standing desk" or "treadmill desk" are getting more and more popular in modern office environment to replace traditional sedentary workstations. One main reason for many occupants to adopt standing and treadmill desks is the effectiveness of these workstations on increasing daily energy expenditure, and thus occupants could reduce their weight while improve health [7–9].

While standing and treadmill workstations are becoming popular, it is unknown if current thermal environments would satisfy occupants who are using those active workstations since metabolic rate would be higher. It is also unclear if current PMV-PPD based thermal comfort standards, such as ASHRAE 55 [10] and ISO 7730 [11] that are mainly applicable to sedentary activity, would be able to predict thermal comfort and provide reasonable design guidelines for spaces with active workstations. Metabolic rate (met) is the parameter which has been least studied among the six main variables of thermal comfort [12]. Due to the increased heat generated within the body with increased metabolic rate, a person's preferred neutral temperature should decrease to maintain the human body heat balance [13] [14]. McNall et al. [15] tested 420 human subjects (210 females and 210 males) dressed in 0.6 clo with three metabolic rate conditions (1.7, 2.2, 2.8 met) at temperatures from 12 to 26 °C, finding neutral temperatures of 22, 19 and 16 °C respectively.

The PMV model, developed by Fanger [16], was built based on three basic assumptions of conditions for thermal comfort. The first one is that human body must be in thermal balance, the second and third

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assumptions are that for a person in thermal comfort at a given activity level, his skin temperature and sweat secretion must remain in certain ranges. By reviewing historical data, Fanger constructed equations that predict comfortable skin temperature and evaporative heat loss from low activity levels. These equations were validated by Olesen et al. [17], who investigated human comfortable physiological state for different combinations of activity, clothing, temperature, humidity and air speeds. Finding that comfortable skin temperature and sweat rate are independent of environmental parameters and clothing levels, but they are depend on activity. Nielsen et al. [18] investigated 10 subjects dressed in shorts with different continuous and intermittent activities, found that the preferred temperature was 19 °C at 2.6 met and 18 °C at 5.0 met., and the skin temperatures and sweat rates preferred for comfort depend upon activity level. Similarly, McIntyre [19] also noted that comfort during exercise is achieved at an air temperature that produces a skin temperature below the sedentary level of about 34 °C but not low enough to suppress sweating. By comparing PMV prediction and field data, Humphreys and Nicol [20] pointed out that PMV predicts well when metabolic rate is lower than 1.4 met, beyond this large discrepancy would occur between PMV predictions and actual thermal sensation votes. A recently study by Wang et al. also found that the relation between comfortable skin temperature and metabolic rate for Chinese people in moderate activity did not agree well with Fanger's equation [21], suggesting Chinese people tended to have higher comfortable skin temperature than PMV prediction.

Preferred temperature method is a way to determine the comfortable temperature directly by allowing subjects to change the chamber temperature based on their preferences. Numerous studies using this method have been conducted to evaluate the validity of PMV model for different geographic locations [22] [23], different times of the day [24] [25], aged and gender [26–28]. It was found that PMV prediction matched preferred temperature well under sedentary activity, and there was no difference in terms of preferred temperature for different geographic locations, aged and gender, or times of the day. However, to date there is no study on preferred temperature at higher office activity levels. In the study by Nielsen et al. [18] on validating Fanger's comfort equations, they asked the exercising subjects every 10 min throughout the experiment whether he would prefer the environment to be warmer, cooler, or the same, and then altering the ambient temperature accordingly. Subjects in this study were professional athletes dressing only shorts while doing physical exercise rather than office activities. And their preferred temperature at each metabolic level were not sufficiently reported in the paper.

In order to provide comfortable environments for occupant with active workstations, we need to (1) quantify the metabolic rates for occupants with these new active workstations, and (2) understand their impact on thermal comfort. The objective of the study is to investigate human preferred temperature with active workstations and compare the results with PMV model predictions. The findings would shed lights in office environment design with active workstations.

2. Methods

The experiments were conducted in the climate-controlled chamber at Xi'an University of Architecture and Technology in December 2017. Outdoor temperature was around 0–10 °C.

2.1. Participants

Twenty subjects, all were university students (10 females and 10 males), participated in all four test conditions, which will be described later in Table 2. They were dressed in standard uniforms totaling 0.6 clo: long-sleeves cotton shirt, long pants, and the subjects' own underwear, sneaker and socks, as visible in Fig. 1. Before selecting the subjects, background surveys were performed to gather basic information such as height, weight, age, weekly exercise, tobacco use, and caffeine consumption. Only people in good health condition were recruited. Before conducting the experiment, the subjects' height and weight were measured on a medical height measurement instrument and a balance with a resolution of ± 2 g (PESA CB 2.2–100, PESA Ltd, Beijing, China). Their anthropometric data is summarized in Table 1. The study was approved by the Committee for the Protection of Human Subjects of Xi'an University of Architecture and Technology.

2.2. Facilities and measurements

Fig. 1a shows the experimental set-up in the climate chamber. Chamber A (measures 3.0 m × 2.4 m × 2.1 m) was used to simulate a typical office environment, it can control temperature to an accuracy of ± 0.2 °C, and RH ± 5%. Mean radiant temperature was controlled to be equal to air temperature, and air speed was less than 0.1 m/s. Air was supplied from the ceiling and returned from the lower side. The chamber can increase/decrease ambient temperature at 0.3–0.4 °C/min after a temperature setpoint change. The other chamber (Chamber B measures 4.5 m × 3.9 m × 2.7 m) was controlled at 26 °C and used as the pre-condition room and changing room.

Table 2 shows the test conditions. The temperature in the chamber A was controlled at 25.7 °C initially for the first 30 min, then the temperature was controlled by subjects for 60 min, under each of the four activity levels described below, in four separate tests. Relative humidity and air velocity were controlled at 50% and less than 0.1 m/s throughout the test. Four activity levels were tested, including sitting and typing (SED), standing and typing (STD), walking at 1.2 km/h and typing (TRD1), walking at 2.4 km/h and typing (TRD2). At SED condition, subjects seated in a plastic mesh chair that provided negligible additional insulation in front of a normal office desk (Fig. 1b). For STD condition, subjects stood for 1 h, with a height-adjustable desk (IKEA SKARSTA) (Fig. 1c). For TRD1 and TRD2 condition, subjects walked on a treadmill (LifeSpan TR1200B, LifeSpan Fitness/P. C. E. Inc. USA) with the speeds set at 1.2 km/h and 2.4 km/h, together with the same height-adjustable desk (Fig. 1d). During all tests subjects were asked to perform office activity (typing) through out the 1 hr test period.

The environmental parameters, including ambient temperature, air velocity, relative humidity, and globe temperature, were measured with the laboratory grade equipment according to ISO7726-1998 specification [29]. Air temperature and relative humidity (TD/TR-72ui datalogger, accuracy ± 0.25 °C, ± 2.5%) were measured at three heights (0.1 m, 0.6 m, and 1.1 m). Globe temperature (HQZY-1, TianJianhuayi Co., Ltd, Beijing, China, accuracy ± 0.3 °C), and air speed (WFWZY-1, TianJianhuayi Co., Ltd, Beijing, China, accuracy ± 0.05 m/s) were measured at 1.1 m height. The sample rates were 1 min for all physical measurements.

Physiological measurements Fig. 2 shows the equipment used for physiological responses in this study. Metabolic data were collected using the COSMED K5 wearable metabolic system (COSMED K5, COSMED S.r.l.,Italy) for each subject at the last 10 min in all tests (Fig. 2a). The K5 was calibrated on gas sensors, flowrate, and pressure before each testing. It uses a face mask that covered both the mouth and the nose to collect expired gas from the subjects, and the captured gas was analyzed in micro-dynamic mixing chamber provided oxygen consumption rate (VO_2), carbon dioxide output (VCO_2), ventilation (VE), and respiratory exchange ratio. The metabolic rate was then determined by measured VO_2, VCO_2, respiratory quotient (RQ), and A_{DU} according to equations (1)–(3) provided by ISO 8996 [31], as follows:

$$RQ = VCO_2 / VO_2 \tag{1}$$

$$EE = (0.23RQ + 0.77) *5.88 \tag{2}$$

$$M = EE*VO_2 / A_{Du} \tag{3}$$

Where: