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An experimental study of the effect of different starting room temperatures on occupant comfort in Danish summer weather

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ABSTRACT

As office workers will usually have a slightly elevated metabolic rate when arriving at work, they may prefer a room temperature below the comfort range for sedentary activity in the morning. This possibility was studied in an experiment with 25 young people, male and female, exposed to four different conditions. Each condition consisted of two sessions, the simulated commute (activity equivalent to walking to work) and the office session. Each office session had a different starting room temperature, namely 18.5 °C, 20 °C, 21.5 °C or 23 °C, followed by an increasing temperature "ramp" of 1.5K every 30 min. During the last 30 min the temperature remained constant. Physical measurements were continuously recorded and subjective evaluation questionnaires were completed every 30 min. It was observed that, upon arrival at the office-lab, a room temperature of 20 °C provided a thermal environment with neutral thermal sensation (0.23), low thermal dissatisfaction (8.6%) and a high level of thermal comfort for the whole body (3.3). It was concluded that, in the cooling season, to improve the thermal sensation of occupants, a lower temperature than is suggested by the existing standards should be maintained in the early office hours, and that this will lead to a lower maximum room temperature during the day, which would result in less demand for cooling during the summer period.

1. Introduction

According to ISO Standard 7730 [1], thermal comfort is "the condition of mind that expresses satisfaction with the thermal environment". Warm or cold discomfort of the whole body, or unwanted heating or cooling of a human body part, can cause dissatisfaction and lead to thermal conditions being judged unacceptable. Several studies have correlated thermal discomfort with low productivity in school and office working environments [2–4]. In addition, according to Wyon and Wargocki [5], thermal discomfort also causes distraction, generates complaints and increases the intensity of Sick Building Syndrome (SBS) symptoms. SBS symptoms include headache, nose irritation (stuffy, running), irritated throat, fatigue, dry eyes, difficulty in concentrating, a lack of alertness etc. The literature shows that increased room air temperature resulted in increasing the intensity of symptoms of fatigue, headache and difficulty in concentrating [6], [7]. A field study conducted in an office building, showed that lower temperature, even within the comfort range, reduced the intensity of SBS symptoms [8].

Due to fluctuations in solar heat gains, occupancy level and equipment, steady-state conditions are rarely observed in practice. Nevertheless, the majority of human subject experiments examining thermal comfort have been conducted under steady-state conditions and in a thermally uniform environment [7] [9–16] or in a non-uniform but constant thermal environment [8] [17–22]. Only a few studies have been conducted under transient uniform conditions. Kolarik et al. examined different temperature ramps and observed a linear relationship between mean thermal sensation and operative temperature [7]. In another study examining thermal sensation under transient conditions for sedentary unclothed men, it was found that when the temperature was increasing, the rate of rise of skin temperature caused a sensation that reduced the discomfort caused by the lower skin temperature [15]. Griffiths and McIntyre examined steady state and 3 levels of temperature ramps, both increasing and decreasing, and developed a method for estimating the degree of dissatisfaction produced by temperature changes [23]. Goto et al. investigated the impact of different activity intensity and duration on thermal sensation and concluded that participants' thermal sensation was more sensitive to changes in core temperature caused by a reduction in activity than by increased activity [24]. McIntyre and Gonzalez examined the impact of clothing insulation and activity level on men's thermal sensitivity during rapid temperature drops and found that for resting subjects, thermal sensitivity was not affected by clothing insulation or season [25]. A literature

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review study of thermal comfort in transient conditions showed that ramps between 0.5 K/h and 1.5 K/h have no impact on the range of the comfort zone [26]. In all of these studies, either the participants had been acclimatized for a period of time in an environment similar to that of the experiment, to negate any effect of previous activities, or no information was provided about their previous metabolic rate. No study was found that correlated thermal sensation in an office environment with previous activity, e.g. commuting on foot or bicycling.

Adaptive thermal comfort has attracted the attention of the thermal comfort community and has been implemented in ASHRAE and CEN standards [27], [28]. The principle of the adaptive approach is that occupants have the possibility to adjust their clothing level, open or close the windows, draw the curtains to reduce solar heat gains, etc. Moujalled et al. conducted a field study in four office buildings in southeast France during Summer-Autumn and found that the subjects' vote was in close agreement with the adaptive control for naturally ventilated buildings [29]. In another study, a survey was conducted in nine schools in Australia during summer and it was found that the more thermally sensitive group of students originated from naturally ventilated schools than air-conditioned schools [30]. Damiati et al. conducted a field study in 13 office buildings in Malaysia, Indonesia, Singapore and Japan running in three different modes (heating, cooling and free-running mode) and found that the results for the free-running mode very mostly within the comfort range of EN 15251 [27]. They also observed that the most frequent personal adaptive behaviour varied among the four countries, namely, turning on the air-condition in Malaysia, or drinking cold beverages in Indonesia and Japan [31]. Liu et el. introduced a method to quantify the physiological, behavioural and psychological portions of the adaptation process and concluded that the physiological adaptation was the dominant factor in the creation of an acceptable thermal environment [32]. It should be stated though, that the adaptive approach incorporated in standards is used for the evaluation of buildings where no mechanical system is in use for the condition of the indoor temperature, and the occupants have the freedom to open or close the windows and adjust their clothing level.

Most offices need cooling even in temperate climates like Denmark due to more airtight building envelopes. Several papers and studies show the benefits of using night cooling combined with the active use of thermal mass in the building [33–37]. These benefits are mainly due to transferring some of the cooling from day-time to night-time and reduction of the peak load. During night-time the potential for using free cooling (evaporative cooling, increased ventilation with cooler outside temperatures) and the use of lower electricity rates, will result in significant energy benefits. During the day the temperature drifts upwards due to solar heat gains and the internal loads from occupants and equipment. It is however important that the temperature drift within the comfort zone [27], [28]. The study by Kolarik et al. showed that a drift even up to 4.8 K/h was acceptable as long as the room temperature stayed in the comfort range [7].

In the existing standards [27] [28], there is a seasonal effect on both the adaptive model and the PMV-PPD approach mainly due to change in clothing level from winter to summer. The effect of a change in metabolic rate (activity level) during the day on the acceptable room temperature has not been studied in detail. Most people will have an increased activity (higher than sedentary) coming to work. This may result in a feeling of warmth arriving in an office controlled for sedentary comfort. A little lower temperature than the comfort range may improve the comfort when arriving in the office and at the same time increase the potential use of night-cooling. The present study investigated that issue, focusing on the conditions in office buildings that can exploit the possibility of night-cooling.

The aim of this study was to examine the impact of increased metabolic rate on thermal sensation when entering an office room that has a lower temperature than is recommended by European Standard 15251 [27]. The authors conducted a human subject experiment in which the effect of commuting to work on foot (estimated and planned to be 2 met on average) was taken into consideration when the participants were asked to evaluate thermal sensation, acceptability and comfort when entering a climate chamber simulating an office space.

2. Experimental methods

The experiment was carried out in the climatic chambers of the International Centre for Indoor Environment and Energy (ICIEE) at the Technical University of Denmark (DTU) in the period mid of April to beginning of May. Based on the Köppen-Geiger climate classification, Copenhagen is classified as category Cfb, namely, temperate oceanic climate, fully humid with a warm summer. Chamber 3 was constructed to accurately control the thermal environment [38]. Its dimensions are 5 m × 6 m x 2.5 m and the walls are made of two layers of porous vinyl sheets. Air was supplied to the chamber through the floor (equally distributed), and by penetrating the vinyl wall-sheets. This construction ensured identical room air and mean radiant temperature, and consequently an operative temperature equal to air temperature. Prior to the experiment, the authors took air speed measurements in several locations inside the room, using heat dummies in the positions to be occupied by the subjects, to simulate the conditions and the heat gains of the actual experiment. This pre-test study of the distributed physical room conditions was conducted to ensure that the office-lab had the standardized acceptable room conditions without causing any draft, thermal discomfort or air movement discomfort. The anemometers were installed on a vertical stand at 0.1 m, 0.3 m, 0.6 m, 0.9 m, 1.1m, 1.4 m, 1.7 m, and 2 m above the floor to examine the vertical stratification. The highest air speed measured was 0.09 m/s, which was considered unlikely to affect the thermal comfort of the participants. Fig. 1 shows the results of the air speed measurements, while the location of the points of measurement are shown in Fig. 2.

Initially, 30 DTU students were recruited and allocated randomly to groups of five. Their age varied from 22 to 27 years old, they were healthy and physically fit and they all had a normal Body Mass Index (BMI), namely between 18.5 and 25 kg/m^2. BMI is obtained by dividing a person's weight (in kg) by the square of his/her height (in metres). The participants were requested to wear light summer clothing and this resulted in an effective clo-value of 0.5 when the insulation of an office chair was included (ASHRAE Standard 55 Table 5.2.2.2C [28]). Each subject participated in four different sessions, experiencing each session only once. Two sessions were executed per day, one starting at 8:30 and one starting 13:00. To minimize possible bias caused by the order of exposure, the four sessions were spread randomly during the three weeks of the experiment, and it was ensured that no participant would come twice on the same day or on consecutive days. By the end of the experiment, only 25 subjects had participated in all four sessions, so only their responses were processed. Due to absence, the number of participants in each session varied from three to five, as is common in an open-office work situation. Table 1 shows the anthropometric information for the 25 remaining participants.

Each session consisted of two phases: the commute phase, which simulated commuting to work on foot, and the office phase. This climatic chamber was furnished to represent a five-person landscape office: each participant was provided with a desk, a chair, and a laptop connected to the internet. Upon arrival, all participants were fitted with a heart rate sensor. In addition, four iButton skin temperature sensors (accuracy ± 0.5 °C) were placed on each participant, on the forehead, the right palm, the right scapula and the right shin, so that local skin temperature and an estimate of the area-weighted mean skin temperature could be recorded. The level of skin temperature can cause both local and whole body thermal discomfort. Therefore, the authors recorded the participants' skin temperature to examine whether any extremely low or high skin temperature values were recorded. Heart rate and skin temperature were measured throughout each session.

The first part of the experiment was conducted in a HVAC controlled office room with a view of the garden outside. In this room the average