Building and Environment 94 (2015) 144–154

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Effects of temperature steps on human health and thermal comfort

Jing Xiong [a], Zhiwei Lian [a, *], Xin Zhou [a, c], Jianxiong You [b], Yanbing Lin [b]

[a] Department of Architecture, School of Naval Architecture, Ocean & Civil Engineering, Shanghai Jiao Tong University, Shanghai, PR China
[b] The Third People's Hospital Affiliated to School of Medicine, Shanghai Jiao Tong University, Shanghai, PR China
[c] Shanghai Research Institute of Building Sciences, Shanghai, PR China

ARTICLE INFO

Article history:
Received 17 April 2015
Received in revised form
17 July 2015
Accepted 31 July 2015
Available online 4 August 2015

Keywords:
Temperature steps
Health symptoms
Fatigue
Thermal comfort
Skin temperature

ABSTRACT

Human beings are often likely to expose themselves to sudden temperature change in daily life. For example, when entering/exiting an air-conditioned building from/to outdoors people may suffer not only thermal discomfort but also even some potential health problems. In this study, the influence of different air temperature step-changes (S5:32°C-37°C-32 °C, S11:26°C-37°C-26 °C, and S15:22°C-37°C-22 °C) on human health and thermal comfort was studied with 24 volunteered participants in the laboratory experiment. Results show that perspiration, eyestrain, dizziness, accelerated respiration and heart rate are sensitive self-reported symptoms in response to temperature step-changes. Thermal sensation, comfort and acceptability just before temperature step are significantly distinguished from that immediately after step change except for thermal comfort and acceptability in up-step of S15 (22 °C-37 °C). Hysteresis phenomenon appears when subjects move from neutral to warm environment. Psychological lead occurs after both up-steps and down-steps. Temperature step magnitude and changing direction have significant impact on human response to temperature steps.

1. Introduction

Human beings are often likely to expose themselves to sudden temperature changes in daily life. For example, people will encounter temperature steps when entering or existing air-conditioned buildings, getting on or off planes, etc. For decades many studies have been carried out to exam influence of temperature steps on human, as described below. Gagge exposed three male subjects to different temperature steps and first discovered the phenomena of overshooting and hysteresis in thermal sensation in response to sudden cooling and heating, respectively [1]. De Dear reported that immediate sensation resulting from temperature up-steps closely resembled later steady state response to the warm environment while initial impression of temperature down-step were typically twice the magnitude of their up-step counterparts [2]. Chun concluded that previously experienced temperatures also affected thermal comfort at the following point in the sequence [3]. Lomas proposed and validated a model to predict dynamic thermal sensation in transient conditions [4]. Nagano exposed 30 male subjects to temperature down-steps (37-31/28/25 °C, 34-28/25/22 °C) and regressed two equations to express the change in the neutral temperature with time [5]. Zhao observed that overshooting occurred when temperature step being larger than 5 °C [6] whereas Chen found that no remarkable physiological variations were detected under step change of 4 °C [7]. Zhang revealed that both skin temperature and its change rate over time had significant impact on thermal sensation [8]. Liu and Du implied heat loss from skin surface could be used as an index to predict thermal comfort after temperature step changes [9,10].

However, previous studies mainly focused on thermal comfort while little attention was paid to human health like self-reported health symptoms and fatigue after step changes. Besides, only few studies have investigated the effect of temperature steps being to equal magnitude but opposite direction transients. Moreover, none of ISO 7730 [11], ASHRAE Standard 55 [12] and EN15251 [13] have declared proper temperature step between two spaces. So, more fundamental researches are in need.

In this study, we carried out an experimentation to study human responses comprising self-reported health symptoms, fatigue and thermal perceptions to both temperature up-steps and down-steps, aiming to provide basic data for understanding of human reactions to step changes. The specific objectives are fourfold:

1) Observing dynamic features of human response to temperature step changes.

* Corresponding author. Room 405, Mulan Chu Chao Building, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, PR China.
E-mail address: zwlian@sjtu.edu.cn (Z. Lian).

http://dx.doi.org/10.1016/j.buildenv.2015.07.032
0360-1323/

2) Finding the most sensitive self-reported health symptoms and fatigue subtypes.
3) Inspecting the effects of temperature step magnitude and direction on human response.
4) Studying the relationship between thermal comfort and skin temperature.

2. Methodologies

2.1. Experimental conditions

The experiment was conducted in a climate chamber which contained two adjacent rooms (Room A: 3.8 m*3.6 m*2.65 m, Room B: 3.8 m*3.8 m*2.65 m) connected by an interior door (Fig. 1). The temperature in Room A was set at 37 °C to represent the outdoor temperature while the temperature in Room B was set at 22/26/32 °C to represent typical temperature levels found in air conditioned and naturally ventilated indoor thermal environments in summer. Hence, we created three kinds of temperature step conditions, namely, S5:32°C-37°C-32 °C, S11:26°C-37°C-26 °C, and S15:22°C-37°C-22 °C. The measured physical parameters describing the indoor environment are summarized in Table 1. The relative humidity in all rooms was controlled within the range of 30%–70%. Air speed was kept under 0.1 m/s and mean radiant temperature was close to air temperature during the experiment.

2.2. Participants

Twenty four healthy college students were recruited as subjects. Their anthropometric information is shown in Table 2. All subjects' BMI lay in the normal range [14]. Skin surface area was calculated based on Chinese formula [15]. All of them were not currently taking prescription medication and were asked to avoid caffeine, alcohol, and intense physical activity at least 12 h prior to the experiment. Females were free from menses during their experiment periods. Participants were required to wear short-sleeved T-shirts, short trousers and slippers, and were informed to avoid toilet and drinking behaviors during the experimental period before each test. All protocols were approved by the university's ethics committee. Verbal and written informed consent was obtained from each subject prior to the participation.

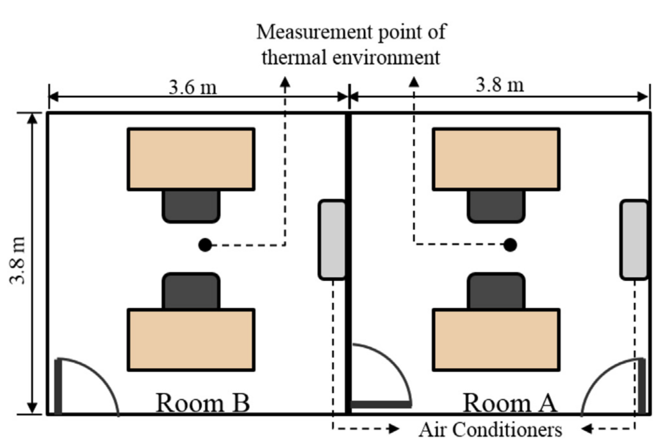

Fig. 1. The climate chamber.

2.3. Measurements

2.3.1. Physical measurement

The temperature (TR-72, Japan), relativity humidity (TR-72, Japan) and velocity (TESTO 425, German) of the air were recorded at 0.1 m and 1.1 m height. The mean radiant temperature was computed from the globe temperature, which was measured using a 150 mm diameter black globe thermometer.

2.3.2. Psychological and physiological measurements

Psychological measurements including health self-reported symptoms, fatigue, thermal sensation (TSV), thermal comfort (TC), thermal acceptability (TA) and endurance were performed by questionnaires.

2.3.2.1. Health symptoms. Subjects were asked to answer whether or not they were suffering from health symptoms like perspiration, nausea, dizziness, accelerated respiration, itchy throat, sneezing, eyestrain, accelerated heart rate and nasal congestion at the moment.

2.3.2.2. Fatigue ratings. Fatigue was assessed using Japanese subjective fatigue symptoms (2002 version) listed in Table 3 [16]. The fatigue check-list contains 25 items and is divided into 5 subtypes. The participants answered each items using 5 point scale from +1(none) to +5(extremely severe). Fatigue subtype score ranges from 5 to 25 because it is the summation of corresponding five items. Similarly, the total score ranges from 25 to 125 since it is the summation of all 25 items.

2.3.2.3. Thermal sensation/comfort/acceptability and endurance. Occupants gave their subjective thermal sensation, comfort and acceptability on continuous voting scales (Fig. 2). Meanwhile, endurance scale containing four levels, namely +1 (no discomfort), +2 (slightly discomfort), +3 (discomfort but I can endure) and +4 (I can't endure any more, stop the experiment) was applied. The test would be immediately ceased if any subject reports +4. Actually, no such circumstance occurred in the experiment.

There are many physiological indexes applied in the field of thermal comfort, and skin temperature was chosen for the present study. Skin temperature was measured using PyroButton (OPULUS Ltd, America) with a precision of 0.2 °C and a resolution of 0.0625 °C. Subjects' local temperatures were measured on 7 body parts, that are forehead, thorax, lower arm, hand back, upper leg, lower leg and instep, and the mean skin temperature was calculated according to Eq. (1) [17].

$$t_{msk} = 0.07t_{\text{forehead}} + 0.35t_{\text{thorax}} + 0.14t_{\text{lower arm}} + 0.05t_{\text{hand back}} + 0.19t_{\text{upper leg}} + 0.13t_{\text{lower leg}} + 0.07t_{\text{instep}} \quad (1)$$

2.4. Experiment procedure

The experiment was performed in July and August, 2014. The effect of three temperature steps (S5, S11, S15) on human was studied. Within-subject design and completely balanced experiment design were applied for this experiment. In order to erase the effect of previous condition on the following condition, the time interval between conditions is 2 days for every subject. Considering the diurnal changes in subjective perception and physiology, all tests were performed in the afternoon.