Energy and Buildings 113 (2016) 87–98

Contents lists available at ScienceDirect

Energy and Buildings

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

# Potential indicators for the effect of temperature steps on human health and thermal comfort

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ARTICLE INFO

*Article history:*
Received 8 August 2015
Received in revised form 14 October 2015
Accepted 16 December 2015
Available online 21 December 2015

*Keywords:*
Temperature steps
Health
Indicators
Thermal comfort
Biomarkers
Physiological parameters

ABSTRACT

This study explored human physiological and biochemical responses to temperature steps. Experiments with three step-change conditions (S5: 32 °C-37 °C-32 °C, S11: 26 °C-37 °C-26 °C, and S15: 22 °C-37 °C-22 °C) were conducted with 24 volunteered participants. Various biomarkers and physiological parameters, reflecting functions of immune system (serum level of IL-6 and HSP70), thermal metabolism system (oral temperature and skin temperature), respiratory system (RR and $SPO_2$) and cardiovascular system (HR and HRV measures), were recorded. The statistical analysis shows that IL-6, oral temperature, skin temperature, HR and HRV are sensitive to temperature step changes. Moreover, both temperature step intensity and direction have significant impacts on human physiological parameters. Human responses of skin temperature and HRV (RMSSD and LF/HF) are significantly more sensitive to temperature down steps, indicating that the risk of down-step may be more serious than that of its up-step counterpart. In addition, significant relations were observed between subjective perceptions and physiological parameters with the method of canonical correlation analysis.


## 1. Introduction

With the extensive application of air conditioners, people often encounter temperature steps when entering indoor from outdoor or moving to outdoor from indoor, getting on or off planes, etc. Sometimes people even have to undergo repeated temperature steps. Temperature steps are generally recognized as a factor of human thermal comfort and health.

For thermal comfort in step-change transient thermal environments, nearly all studies relating to thermal comfort contained information of subjects' thermal perceptions. Gagge first discovered the phenomena of hysteresis and overshooting in thermal sensation [1]. Following studies [2–10] also investigated human dynamic subjective perceptions. Other than the extensive application of questionnaires, only a limited number recorded physiological parameters among which skin temperature was the most frequently used one. Contrary to subjective perceptions, no overshooting was observed in skin temperature [1,3,6–8]. Chen et al. [5] also examined other skin parameters including skin capillary blood flow, skin moisture and transepidermal water loss. Apart from skin physiology, other physiological indicators were seldom explored.

As far as human health is concerned, indoor environment is usually considered to be health-related [11–14]. Temperature step is a kind of environmental stressor and associated with health. When encountering temperature step, human internal organs will activate or suppress accordingly to accommodate stress. Health effect of temperature step may be not instant but rather get delayed as most biometeorological studies reported that both temperature and diurnal temperature range have lag effects on human health [15,16]. Not immediately pathogenic although one-time sudden temperature change may be, its effect on human body does exist and people are very likely to get sick under multiple temperature steps which would cause repetitive stress responses. For example, it had been suggested that repetitive activation of the cardiovascular defense response may lead to hypertension [17]. For susceptible populations like the elderly and patients, sustained activation existed although stressor had been removed and it may result in the occurrence of some diseases [18].

There are many epidemiological field surveys that indicates temperature steps may be one factor of human health. Shanyuan and Lihua [19] conducted field survey and believed that the occurrence of SBS might be caused not only by poor indoor air quality but also the relatively larger temperature difference between indoor and outdoor. Ruojing [20] analyzed 56 clinical cases and concluded

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http://dx.doi.org/10.1016/j.enbuild.2015.12.031
0378-7788/

**Nomenclature**

| | |
|---|---|
| ANOVA | analysis of variance |
| SBS | sick building syndrome |
| IL-6 | interleukin-6, ng/L |
| HSP70 | heat stress protein 70, ng/L |
| $T_{skin}$ | mean skin temperature, °C |
| $T_{oral}$ | oral temperature, °C |
| $SPO_2$ | blood oxygen saturation, % |
| RR | respiratory rate, BPM |
| ECG | electrocardiograph |
| HRV | heart rate variability |
| HR | heart rate, BPM |
| mRR | the average of the beat intervals, ms |
| SDRR | standard deviation of the beat intervals, ms |
| RMSSD | the square root of the mean of the sum of the squares of differences between adjacent beat intervals, ms |
| TP (5 min total power) | the variance of NN intervals over temporal segment, $ms^2$ |
| $LF_{norm}$ | LF power (0.04–0.15 Hz) in normalized units; LF/(TP-VLF) × 100, n.u. |
| $HF_{norm}$ | HF power (0.15–0.4 Hz) in normalized units; HF/(TP-VLF) × 100, n.u. |
| LF/HF | ratio LF/HF |

that the temperature gap was one of the most important factors for air conditioner syndrome. An large sample investigation in Jiangsu and Shanghai found that lower indoor temperature which generated large temperature gap between indoor and outdoor is closely related to the higher risks of discomfort in nervous system, digestive system, respiratory system, skin and mucous membranes [21].

Physiological measurement is the stage next to field studies and it aims to analyze to what extents the influence of different temperature steps can be to human body [21]. However, few researches conducted well-controlled chamber studies from the aspects of physiology and biochemistry. Huizenga et al. [22] recorded body core temperature and skin temperature in response to whole-body cooling and heating. Zhang et al. [6] monitored HR several times during the exposure. But they did not give a further discussion. Yu et al. [9] measured some physiological parameters including rectal temperature, skin temperature, sweat rate, HRV and HSP70. However, Yu only studied effect of a temperature step changing from 26 °C to 36 °C and emphasized on thermal adaptability difference between people who were accustomed to air-conditioned environments and naturally ventilated environments respectively.

Body heat is gained from the environment and produced by metabolism. The overall load must be dissipated to maintain a body temperature of 37 °C [23]. When subjects encountered a sudden temperature step, peripheral and central temperature receptors sense the change and deliver information to thermoregulatory center (hypothalamus). The hypothalamus integrates information, and then initiates the process of thermoregulation through autonomic nervous system (ANS), somatic nervous system and hormone secretions. Parasympathetic nervous system and sympathetic nervous system make up ANS, and their centers lie in posterior and anterior hypothalamus, respectively. They interact with each other to control most of the body's internal organs such as heart, lung, vessels, etc.

In order to find potential indicators for the effect of temperature steps on human health and thermal comfort, we recruited 24 volunteered subjects and conducted an experiment with the utilization of various biochemical and physiological parameters. The specific objectives are manifold.

(1) Observing dynamic features of human biochemical and physiological responses to temperature step changes.
(2) Inspecting the effects of temperature step magnitude and direction on human responses.
(3) Studying the relationship between subjective perceptions and objective parameters.
(4) Recommending sensitive physiological parameters to future temperature step studies.

## 2. Methodologies

### *2.1. Experimental facilities and conditions*

The experiment was carried out in a climate chamber. The chamber 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) that were connected by an internal door. Temperature in Room A was maintained at 37 °C to simulate the outdoor temperature in the summer while temperature in Room B was set at 22/26/32 °C to represent typical temperature levels found in air conditioned and naturally ventilated buildings in the summer. By this means, we developed three 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 air temperatures did not significantly deviate from the intended levels. The relative humidity in all rooms was controlled in 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. Subjects*

Twenty four healthy subjects were recruited in the study, including twelve men (mean ± S.D. of age: 22 ± 1 years, height: 176.8 ± 4.9 cm, weight: 66.5 ± 6.3 kg) and twelve women (mean ± S.D. of age: 22 ± 1 years, height: 164.1 ± 5.7 cm, weight: 55.1 ± 4.0 kg). All subjects' body mass index lay in the normal range [24]. Participants were required to wear short-sleeved T-shirts, short trousers and slippers (an estimated clothing insulation value of 0.5 clo). All protocols were approved by the university's ethics committee. Verbal and written informed consent was obtained from each subject prior to the participation.

### *2.3. Measurements*

#### *2.3.1. Physical measurements*

The measurement site is placed at the center of the each room. The air temperature and relative humidity were recorded every 10 s with data loggers (TR-72, Japan) at 0.1 m and 1.1 m height. The air velocity (TESTO 425, German) was also monitored. The mean radiant temperature was computed from the globe temperature, which was measured using a 150 mm diameter black globe thermometer.

#### *2.3.2. Biochemical measurements*

IL-6 and HSP70 are potential indictors to reflect the reaction of immune system to temperature steps. IL-6 is one of the proinflammatory cytokines. It can singly or in combination with other cytokines exhibit numerous redundant effects that promote fever, produce local inflammatory signs, and trigger catabolic responses [25]. IL-6 is also reported to be related to heat stress and many other diseases [23,26]. It can be treated as an indicator to reflect immunity-specific homeostasis. As for HSP70, nearly all cells respond to intensive heat stress by producing heat-shock proteins or stress proteins which contains HSP70 [23,27]. Increased levels of heat-shock proteins in a cell induce a transient state of tolerance to a second, otherwise lethal, stage of heat stress, allowing the cell to survive [28].