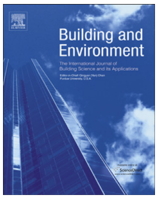
Building and Environment 107 (2016) 254–262

Contents lists available at ScienceDirect

Building and Environment

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



Investigation of thermal perceptions of subjects with diverse thermal histories in warm indoor environment

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ARTICLE INFO

Article history:
Received 27 June 2016
Received in revised form
8 August 2016
Accepted 9 August 2016
Available online 10 August 2016

Keywords:
Thermal history
Perception
Warm indoor environment
Thermal sensation
Air freshness

ABSTRACT

This paper examines the indoor environment perception of subjects having different thermal backgrounds. Two-hour-long measurements have been recorded in a test room and placed in a climate chamber. The ambient temperature was set to 30 °C and the indoor environment parameters were constant during the experiments. Adaptation by clothing adjustment or changing the metabolic activity level was not allowed. Besides the overall acceptance of the environment, subjects had to rate the thermal sensation, odour intensity, air velocity, draught, air freshness and surface temperatures. The thermal sensation was evaluated on a 7-point scale. Subjects coming from regions with warmer climates, being accustomed with air conditioning systems, preferred low indoor temperatures. However, their thermal sensation decreased in the highest rate during the 2 h of measurements. The air freshness and the air velocity were evaluated differently by the analysed groups. The future research will focus on the investigation of the relationship between the operative temperature and perceived air freshness.

1. Introduction

Large transparent surfaces are widely used in office, educational and even residential buildings to provide exciting views, a pleasant ambiance, and proper daylighting for occupants. Nevertheless, in the summer, the heat load caused by solar radiation can lead to overheating. In non-air-conditioned buildings, the occupants might be exposed simultaneously to high mean radiant and air temperatures.

It was shown that in the future, heat waves will become more intense, more frequent and longer-lasting [1]. Coley and Kershaw studied the response of the internal environment within buildings to perturbations in the weather [2]. They found that the relation between the change in the mean or maximum internal summertime temperature and the change in the mean or maximum external temperature is linear.

The climate change has to be taken into account when indoor design temperatures are established or comfort standards are developed. Holmes and Hacker defined ‘switching off’ heat gains as one of the key principles of low-energy design [3]. It was proven that the evaluation of everyday indoor climates using the predicted mean value (PMV) can lead to discrepancies in comparison with the reported thermal sensation of occupants [4,5].

In mechanical cooled buildings the recommended design values for indoor operative temperatures in offices and residential buildings is 25.5–27.0 °C. In these buildings, the deterministic approach of thermal comfort evaluation works well. In free running buildings, the design values for the indoor operative temperature are a function of the exponentially-weighted running mean of the outdoor temperature. In these buildings, the adaptive thermal comfort model gives better results, [6].

In free running buildings, the indoor environment is strongly influenced by the outdoor environmental parameters. It was clearly demonstrated that besides the six well known parameters taken into account in PMV calculation, the thermal sensation is influenced by a series of psychological factors, the expectations of the occupants, gender and age. These parameters are usually unknown to the architects or designers of HVAC systems, so it seems to be impossible to create the “optimal” thermal environment. Furthermore, the work of designers is made more difficult by the fact that in closed spaces the occupants, coming from different countries, are accustomed to different climates and different indoor environments. Fanger and Toftum introduced the expectation factor to

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http://dx.doi.org/10.1016/j.buildenv.2016.08.010
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extend the validity of the PMV model to non-air-conditioned buildings [7]. In non-air conditioned buildings, occupants may utilize different adaptive approaches to achieve thermal comfort [8–11]. There are cases when some of the adaptive strategies cannot be freely used (changing of clothing or position, etc). In such situations, physiological and psychological adaptation strategies are used by occupants to restore their thermal comfort. Nicol and Humphreys suggested an adaptive algorithm for indoor temperature control [12]. The adaptive approach is based on field surveys conducted in a wide range of environments [13–17].

According to de Dear, ‘the context of a person-environment interaction includes, not just environmental context but also cognitive and even emotional context’ [6]. The psychological and thermophysiological aspects of thermal comfort have been presented by Höppe, who discussed the differences between steady-state and non-steady state thermal comfort indices [18]. Haldi and Robinson developed a comprehensive model to predict the probability distribution of thermal sensation in non-air-conditioned buildings [19]. They tried to consider individual diversity as well.

Liu et al. developed a method to weigh the three categories of adaptive thermal comfort [8]. They found that the psychological and behavioural adaptations have almost the same weight. However, their sum in UK is equal to the weight of physiological adaptation; while in China, their sum exceeds the weight of the physiological adaptation. The cumulative result of past thermal experience and the socio-economic environment (habituation) has an important influence on the thermal perception [8].

Hwang and Chen analysed the behaviour and adaptation of elderly people in residential environments [20]. They investigated people in Taiwan older than 60 years and found that the predominant strategy of thermal adaptation was window opening in the summer and clothing adjustment in the winter. Kwok and Rajkovich introduced the notion of the ‘mesocomfort zone’, which takes into account, besides the adaptation, the person's expectations, memories and level of control over the thermal environment [21].

It is common that people with different countries of origin and thermal background work or learn in the same building (office or educational). Fanger discussed the effect of the national-geographic location on the application of the thermal comfort equation [22]. Experiments involving Danish and North American subjects were carried out. The thermal sensation votes showed agreement between the temperatures desired for thermal neutrality for the two national-geographic groups. Ellis did not find differences between the temperature preferences of European and Asian subjects, [23]. Fanger, in his study, referred to the reports of Ambler [24] and Rao [25], who showed that the temperature preferences of European residents in Nigeria and Indian subjects in Calcutta are similar. In each case, the desired temperature was approximately 26 °C. The aim of these experiments was to establish the preferred temperature of persons living or working in different climates.

Luo et al. performed a complex research, including both physiological measurements and subjective questionnaires, in order to analyse the effects of thermal comfort expectations and thermal physiological adaptation on the thermal perception, [26,27]. They focused on the winter period and compared the responses of groups with different thermal histories. Statistical analysis of the two sub-groups who migrated, north or south, indicated that the occupants of the building get accustomed to the thermally neutral lifestyle more easily and faster than do their counterparts who went from thermally neutral indoor climates of the north to the cold and uncomfortable indoor climates of the southern regions of China. Furthermore, their findings suggest that indoor thermal exposures can also influence occupants' thermal adaptation. Chun et al. explored the relationship between thermal history and indoor comfort during the hot season in Seoul and Yokohama, [28]. They concluded that thermal history prior to the chamber experiments influenced the thermal sensation in the chamber.

At the University of Debrecen, Department of Building Services and Building Engineering, a series of measurements has been carried out to test the thermal perception of young people coming from three countries with different climates (Hungary, Nigeria and Turkey). For the Hungarian subjects, the thermal perception analysis was performed by gender, too. Both the mean radiant and indoor air temperatures were set to 30 °C. These temperatures are higher than the recommended design values in air conditioned buildings, but can be experienced during summer, in free running buildings. The main outcomes of the research are presented in this paper.

2. Objectives and hypothesis

The main goal of this research was to analyse the time dependence of thermal perception in warm environments of college-age subjects having different thermal backgrounds. Behavioural adaptation was not allowed during measurements. During experiments the air and mean radiant temperature and the air velocity were kept constant.

It was presumed that the indoor environment is evaluated significantly different by subjects with different thermal backgrounds. Furthermore, it was hypothesised that occupants accustomed to air conditioned indoor environments will not tolerate the warm environment.

3. Methods and equipment

3.1. Test room

In the Indoor Environmental Quality laboratory at the University of Debrecen there is an “adiabatic” room, which has its external building elements very well insulated ($U = 0.19\ W\ m^{-2}\ K^{-1}$). In this external “adiabatic” room, the test room ($2.50 \times 3.65 \times 2.55$ m) is placed (Fig. 1). The space between the walls of these rooms is divided into two temperature zones. There is an “outdoor” temperature zone, where temperatures in the range −20 to 34 °C can be produced. In the other zone the temperatures are similar to the

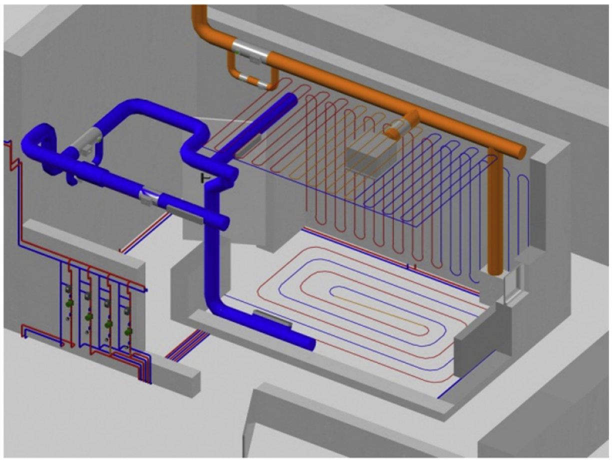

Fig. 1. Test room (IEQ Laboratory).