Available online at www.sciencedirect.com
ScienceDirect
Building and Environment 43 (2008) 877–885
BUILDING AND ENVIRONMENT
www.elsevier.com/locate/buildenv

Thermal diary: Connecting temperature history to indoor comfort

Chungyoon Chun[a,*], Alison Kwok[b], Teruaki Mitamura[c], Norie Miwa[d], Akihiro Tamura[e]

[a]College of Human Ecology, Yonsei University, 134 Shinchon-Dong, Seodaemun-Ku, Seoul, Republic of Korea
[b]Department of Architecture, University of Oregon, 1206 Eugene, OR, 97403-1206, USA
[c]Department of Architecture, Ashikaga Institute of Technology, 268-1 Omae-Cho, Ashikaga City, Tochigi, Japan
[d]Ecological Technology System Laboratory, Yokohama National University, 79-5 Tokiwadai, Hodogaya-Ku, Yokohama, Kanagawa, Japan
[e]Department of Architecture, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama, Kanagawa, Japan

Received 3 August 2006; received in revised form 23 October 2006; accepted 10 January 2007

Abstract

To explore the relationship between thermal history and indoor comfort, surveys and measurements were conducted in Seoul, Korea and Yokohama, Japan. Fifty-two subjects were recruited from university campuses in Seoul and Yokohama during the hot season in August 2002. To collect information regarding people's daily thermal history, background questions (a thermal diary) were completed by subjects during the 24 h prior to entering in a climate chamber. Subjects changed into uniform clothing ensembles and complete thermal diary questions just prior to entering the chamber which was pre-conditioned to 28 °C and 50% relative humidity. Subjects entered the chamber and completed a set of thermal comfort questions at 10-min intervals for 1 h. Thermal history, prior to the chamber experiment, influenced the thermal sensation in chamber. Though the physical conditions in the climate chamber were identical (28 °C, 50% rh), Yokohama subjects responded with cooler thermal sensations than Seoul subjects. These subjects experienced hotter weather conditions (than the Seoul subjects) and voted that they felt cooler than the Seoul subjects who experienced cooler temperatures prior to entering the chamber. It was also found that subjects who use air-conditioning at home responded with warmer thermal sensations than the subjects who did not use air-conditioning. These results indicate that there is a strong interaction and influence of our experience with outdoor weather and our indoor thermal comfort.

Keywords: Thermal diary; Temperature history; Thermal comfort; Climate chamber; Yokohama; Seoul

1. Introduction

With the recent revisions to ASHRAE Standard 55, thermal environmental conditions for human occupancy [1], that includes information about the adaptive comfort model, discussion has centered around the influence of outdoor temperatures on indoor comfort. In fact, much of the standard's revision is derived from a global database of 21,000 measurements that is the basis for determining comfort in naturally ventilated buildings [2]. Outdoor temperatures are closely aligned with indoor comfort in naturally ventilated buildings [3], yet comfort predictions using PMV method were inaccurate in these non-steady-state buildings. Since a person's satisfaction with the thermal environment depends on so many variables such as building form, HVAC function, cultural factors, social norms, and contextual expectations, the revised standard offers an optional method to assist designers in predicting indoor conditions in naturally ventilated buildings. This connection to the outdoor climate lies at the heart of this study. We examine comfort through both a field and chamber experiment to determine the influence of our comfort perceptions during our daily life's routine in and out of buildings (e.g. leaving home, commuting to work, walking outside for lunchtime errands, etc.) to our indoor comfort evaluation.

Current field comfort research typically considers conditions and responses in situ, at a single point in time, while subjects are seated at their desks. Environmental variables are measured within the environment closely surrounding the seated subject, as comfort questions are asked

*Corresponding author. Tel.: +82 2 2123 3138; fax: +82 2 313 3139.
E-mail address: chun@yonsei.ac.kr (C. Chun).

0360-1323/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2007.01.031

simultaneously. As with any survey, these immediate, one-time votes are a function of the response to conditions at that particular moment. What these studies do not account for is thermal experience leading up to the time that the in situ survey is taken. Such information is critical to identifying appropriate thermostat set points to achieve better thermal satisfaction as well as to energy savings.

The purpose of this research is to find out the relation between the indoor thermal comfort and exposure thermal history. However, outdoor weather is a very important factor to decide a people's exposure thermal history. From this reason, this study's results could contribute to clarify the relation between outdoor weather and indoor thermal comfort, not only the exposure temperature history and indoor thermal comfort.

2. Connections between indoor and outdoor comfort

Several studies have examined thermal conditions and comfort during a *travel route* through transient semi-outdoor (dynamic) conditions, in an environmental control chamber and in the field [4,5]. As people entered a building after traversing along a semi-outdoor route, their votes were influenced by the experiences of 30 min before. Questions were raised about the influence of longer comfort experiences like 24 h or day-to-day life.

Humphreys and Nicol, in their presentation of the adaptive approach and model for thermal comfort, state that people "may assess their thermal sensation against some kind of background expectation, which is perhaps informed by recent experiences in the several buildings they have visited or occupied" [11]. They find a strong correlation exists between comfort temperature and mean outdoor temperature, indicating that in office buildings occupants may use a type of "*thermal memory*" to form their expectations for comfort.

In a field study of naturally ventilated and air-conditioned arcades, environmental measurements and thermal comfort assessments were polled from the people to examine *thermal expectation* and *memory*. Subjects took surveys prior to entering the arcade, at intervals during their route through the arcade and again once outside of the arcade. There was little variation in expectation votes for an air-conditioned versus naturally ventilated arcade, to be expected, as subjects were not aware before testing whether the arcades were conditioned or naturally ventilated. Subjects could recall the thermal environmental conditions inside a building, even after leaving the space, though they may tend to overcorrect, remembering a space to be slightly warmer or cooler than actual recorded conditions [6].

The influence of *metabolic changes* on thermal sensation was examined through modified step-changes during the experiment. Increased activity, and even low metabolic activity, prior to an experiment, affect thermal perceptions and preferences of humans [7]. When predicting thermal sensation, a detailed description of the activity during the past 15 min may improve the precision of the vote predicting.

The *effect of exposure to air-conditioned* environments on thermal comfort perception in naturally ventilated buildings in Singapore and Indonesia found for people exposed to air-conditioned spaces for less than 4 h and for more than 8 h per day showed preferences for higher comfort temperatures [8]. People with less than 4 h/day exposure to air-conditioning, may have been acclimatized to the hot and humid environment. People with longer exposure time to air-conditioning were thought to desire warmer temperatures after working inside an air-conditioned office all day.

Clothing adjustments are found to be one of the causal links between indoor thermal comfort and outdoor weather. Evidence from a cross-sectional study of clothing in Australia demonstrates that outdoor temperatures strongly influence clothing worn indoors and no correlation was found to prevailing indoor temperatures [9]. The study suggests that a variable operational set point for air-conditioned buildings, programmed on the basis of a running-mean outdoor temperature would save HVAC energy, potentially increase thermal comfort, and accommodate varying clothing behaviors.

Do thermal sensation votes shift with *expectations* of current weather conditions? One study examined psychological aspects for indoor and outdoor comfort, finding expectation of thermal conditions a major factor in subjective assessment and satisfaction [10]. Studies in urban climatology found passers by on a sunny street canyon voted that they were thermally comfortable, yet if assessed by PMV, the values would have been higher than +3 (hot). Two reasons were attributed to the assessment of perceiving too-hot conditions as comfortable: the prior weather conditions had been unseasonably cold and people welcomed the sun's radiation; people had time off and wanted to get a suntan. Hoppe recognized the difficulty in standardizing the thermal history of the subject, yet it is a necessity when using a dynamic model. If a subject moves from an air-conditioned space to the outdoors, the contrast in thermal sensation is large.

This study explores the dynamic relationship of thermal comfort perception and these subjective factors. Thermal perception is not based on the physical conditions of a single moment, but the dynamic and cumulative processes that we encounter that encourage adaptive behaviors (Fig. 1).

3. Objectives

In this experiment we are attempting to account for the thermal experiences, perceptions, and expectations of subjects leading up to an in situ thermal comfort experiment, not simply collecting information from one building. The objectives of this study are to:

1. Seek a relationship between thermal history and indoor comfort.