Available online at www.sciencedirect.com
ScienceDirect
Building and Environment 42 (2007) 4034–4042
BUILDING AND ENVIRONMENT
www.elsevier.com/locate/buildenv

Effect of humidity on human comfort and productivity after step changes from warm and humid environment

Hitomi Tsutsumi[a,*], Shin-ichi Tanabe[a], Junkichi Harigaya[a], Yasuo Iguchi[b], Gen Nakamura[b]

[a]*Department of Architecture, Waseda University, 3-4-1, Okubo, Shinjuku-ku, Tokyo 169-8555, Japan*
[b]*Technical Research Center, Shin Nippon Air Technologies Co. Ltd., 7033-182, Miyagawa-Sumisujiuchi, Chino, Nagano 391-0013, Japan*

Received 27 March 2006; received in revised form 7 June 2006; accepted 20 June 2006

Abstract

Subjective experiments were conducted to evaluate the effects of humidity on human comfort and productivity under transient conditions from hot and humid environment to thermally neutral condition. Two climate chambers, "Chamber 1" and "Chamber 2", adjoined each other were used for this study. Subjects were exposed to 30 °C/70%RH air in Chamber 1 for 15 min with 2.0 met of metabolic rate. Then they moved into Chamber 2, where 4 humidity conditions, 30, 40, 50 and 70%RH were examined. Air temperature was adjusted to keep SET* constant at 25.2 °C for all conditions. Subjects were exposed in Chamber 2 for 180 min performing 2 kinds of simulated office work.

Positive effects of low humidity on subjective pleasantness were found under transient condition at low humidity due to more evaporation from human body, while no significant difference in thermal sensation and humidity sensation among 4 relative humidity levels was obtained. Subjective performance was found to be at the same level under all conditions. However, subjects reported to be more tired at 70%RH after humidity step change.

Keywords: Humidity; Step change; Comfort; Productivity; Subjective experiment

1. Introduction

In Japan, the "Law for Maintenance of Sanitation in Buildings [1]" is applied to offices whose total floor areas exceed 3000 m^2. It states that the relative humidity in an office space should be kept between 40 and 70%RH. The ASHRAE Standard 55-92 [2] prescribed a lower boundary humidity of 4.5 g/kg, which was equivalent to 30% RH at 20.5 °C. This standard was revised as the ASHRAE Standard 55-2004 [3], which does not specify a minimum humidity level. The ASHRAE Standard 62-2001 [4] recommends the relative humidity of 30–60%RH. These lower boundaries of current humidity criteria are intended to limit the low humidity conditions in winter. However, improvement of recent HVAC technology has allowed engineers to use cold air distribution systems in many office buildings, creating a thermal environment with low humidity during summer. Outdoor air cooling system can reduce indoor air humidity in spring and autumn. Further studies on the effects of low humidity on occupants' comfort and performance in other seasons are needed, as well as in winter.

Tsutsumi et al. [5–7] have reported the effects of low humidity on subjective comfort and productivity under steady-state conditions in summer through the various subjective experiments. Eye comfort of subjects wearing contact lenses at low humidity, thermal comfort and productivity under humidity conditions with different indoor air quality levels, differences of the relative humidity effects and absolute humidity effects on subjective comfort and performance were examined in the series of experiments. For all experiments, SET* was set to be constant at 25.2 °C. As the result, negative effects of humidity were not found in the thermally neutral air at 30%RH under a steady state in summer. Therefore, present study focuses on subjective comfort and productivity under the transient condition.

*Corresponding author. Tel.: +81 3 5292 5083; fax: +81 3 5292 5084.
E-mail address: tsutsumi@tanabe.arch.waseda.ac.jp (H. Tsutsumi).

0360-1323/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2006.06.037

Previous studies on the impacts of humidity step change on people were reviewed. Kakitsuba and Inoue [8] concluded that subjects felt relaxed at low humidity from observed exaltation of high frequency spectrum, 0.15–0.40 Hz, which indicated the parasympathetic nervous system activity. Fukai [9] made subjective experiments simulating transient conditions. Thermal comfort of subjects who walked in hot environments and then entered the indoor environment was examined. Under the low humidity condition subjects felt more comfortable due to quick evaporation of sweat. Ibamoto et al. [10] reported that a low humidity made it possible to provide comfort to both those who are in thermal transient and those who are in a steady state, based on the results of subjective experiments. deDear [11] showed the change of subjective thermal comfort and skin temperature under the conditions, with different clothing at humidity step down and step up. However, only few studies reported the effects of low humidity on not only human comfort but also subjective productivity at humidity step change.

Present paper reports the subjective experiments carried out to clarify the effects of humidity on subjective comfort and productivity under transient conditions, simulating occupants' moving from outdoor with warm and humid air to indoor with thermally neutral conditions in summer. This will be basic data to evaluate effects of the indoor climate, with the dehumidifier on occupants' comfort and productivity when they entered there.

2. Method

Subjective experiments were carried out to evaluate the effects of humidity on human comfort and productivity, simulating people moving from warm and humid condition like outdoor in summer to thermally neutral condition like inside the office. Two climate chambers used for the experiments were adjoined each other as shown in Fig. 1. People can move between the chambers without passing any other room.

A total of 12 Japanese adults of both gender (aged 30–60, mean 40.3) were used as subjects. All subjects participated in all conditions. All subjects were volunteers, who were paid for participating in the experiments. Considering their circadian rhythm, all subjects took part in the experiments at the same time of the day.

A diagram for the environmental conditions is shown in Fig. 2. The environmental conditions are also listed in Table 1. The condition of 30 °C/70%RH was set in Chamber 1, simulating the outdoor climate in summer in Tokyo. In Chamber 2, 4 humidity conditions, 30, 40, 50 and 70%RH were examined. Air temperature was adjusted to keep SET* constant at 25.2 °C for all conditions, assuming air-conditioned office spaces in summer. In both chambers, mean radiant temperature was estimated to be equivalent to air temperature. Air velocity was still for all conditions. Subjects wore clothing ensembles (long-sleeve shirt, trousers, underwear, socks and slippers). All subjects wore their own underwear. Clo value was measured to be 0.67 clo by using a thermal manikin. Measured values of air temperature, relative humidity, air velocity, mean radiate temperature and SET* calculated from these data are also listed in Table 1.

A timetable of the experiments is displayed in Fig. 3. During a 15-min exposure in Chamber 1, subjects were asked to walk up and down. Subjective metabolic rate was assumed to be 2.0 met, simulating a person walking at 3.2 km/h. Just before leaving Chamber 1, skin moisture on left forearm of each subject was measured using SKICON-200 (IBS) [12]. Subjects rated their sensations on the questionnaire using the visual analogue scales. Break-up time (BUT) is one of the physiological reactions that might affect the subjective eye comfort. Wyon and Wyon [13] made experiments in a climate chamber and a car cabin for

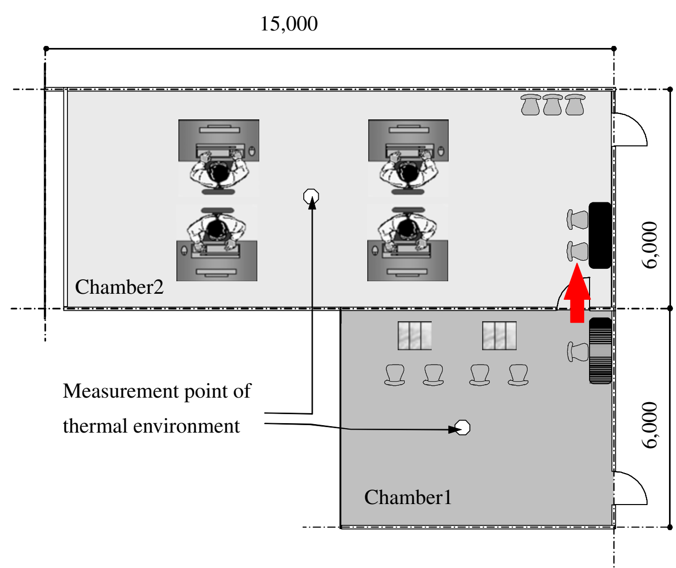

Fig. 1. Plan of climate chambers.

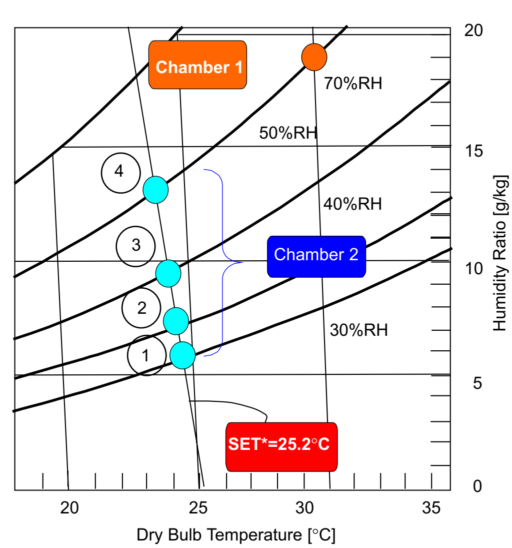

Fig. 2. Diagram for environmental conditions.