Subjective experiments on the effects of relative humidity and humidity ratio during summer season

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ABSTRACT

In order to clarify the effects on comfort and health of relative humidity and humidity ratio, subjective experiments were conducted in a climate chamber in Japan during the summer of 2002. Fifteen subjects were exposed for 180 min, while being engaged in simulated office works and questionnaires. The experiments were conducted at a constant SET* (Standard New Effective Temperature) with six different humidity conditions, namely [30%RH/6.13 g/kg], [37%RH/6.13 g/kg], [37%RH/7.45 g/kg], [45%RH/7.45 g/kg], [45%RH/8.97 g/kg], [55%RH/8.97 g/kg]. The highest skin moisture was observed under 8.97 g/kg conditions. Oral mucosa moisture under 6.13 g/kg conditions was lower than that of other conditions. Subjects felt drier under low humidity within their tolerance level. Though the effects of humidity conditions (37–55%RH) on performance were moderate, subjects complained more of being fatigued under low humidity.

INDEX TERMS

Relative humidity; Humidity ratio; Sensation of dryness; Productivity

INTRODUCTION

The humidity limit defined in 'Law for Maintenance of Sanitation in Buildings' in Japan is 40–70%RH in the offices with central HVAC system whose total floor areas exceed 3000 m^2. On the other hand, the lower boundary humidity of ASHRAE Standard 55-92 (ASHRAE, 1992) is 4.5 g/kg, which is equivalent to 30%RH at 20.5°C. ASHRAE Standard 62-89 (ASHRAE, 1989) recommends relative humidity of 30–60%RH. Both relative humidity and humidity ratio are used in boundaries of humidity.

Previous studies (Tanabe *et al.*, 1994, 1995, 2000, 2001) conducted under constant SET* conditions showed that non-thermal effects were more prominent than the thermal effects in low humidity environments. Proetz (1956) said the dryness of nose would be perceived on 25%RH. Winslow *et al.* (1949) suggested that oral mucosa moisture would be significantly low under the environment of 8.42 g/kg. As for the dryness of eyes, Laviana *et al.* (1988) reported that subjects complained the discomfort of eye under 30%RH environments. Matsubayashi *et al.* (2000) reported that the number of break-up time of eyes (BUT) significantly increased under the environment with humidity ratio lower than 7 g/kg.

The lower boundaries of ASHRAE Standard 62-89 and the law of Japan mentioned above are specified in relative humidity; the lower boundary of ASHRAE Standard 55-92 is given in humidity ratio. Both relative humidity and humidity ratio were used to evaluate the effects of humidity on human being. In this paper, the effects of relative humidity and humidity ratio on occupants' physiology, psychology and performance under constant SET* conditions are reported.

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METHODS

Experimental Design

In order to investigate the effects of relative humidity or humidity ratio, on occupants' comfort and health, subjective experiments were conducted in a climate chamber at Waseda University in Tokyo, Japan, during the summer of 2002. Environmental conditions are shown in Table 1. Diagram of the experimental conditions is shown in Figure 1. Under all the conditions, SET* was kept constant at 25.2°C. The two clothing conditions were estimated to be either 0.6 clo (long-sleeve shirts + trousers + socks) or 1.0 clo (0.6clo clothing + jacket) by ISO 9920. All the subjects wore their own underwear. A total of six conditions of different relative humidity and humidity ratio conditions were utilized. Metabolic rate of the simulated office work was estimated to be 1.2 met. Mean radiant temperature and air velocity were estimated to be equal to air temperature and still, respectively. In order to avoid subjects' learning effects of the simulated office works, a practice session (pre) at SET* = 25.2°C/50%RH was conducted in addition to six conditions at the beginning of the experiments. The experimental conditions were randomly selected.

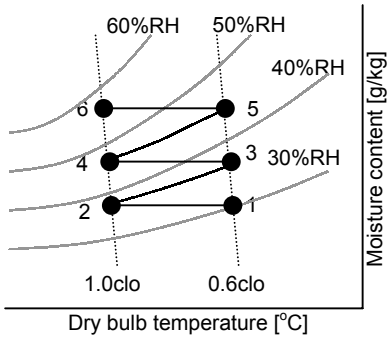


Figure 1 Diagram for environmental conditions.

Table 1 Environmental conditions

	Relative humidity [%RH]	Humidity ratio [g/kg]	Clothing [clo]	Temperature [°C]	Air velocity [m/s]	Metabolic rate [met]	Actual measurement of temperature [°C]	Actual measurement of humidity [%RH]	Calculation of humidity ratio [g/kg]
1	30	6.1	0.6	25.4	0.1	1.2	25.0	37	7.2
2	37		1.0	22.1			21.3	45	7.0
3		7.5	0.6	25.3			25.0	41	8.2
4	45		1.0	21.9			21.0	48	7.5
5		9.0	0.6	25.1			24.9	48	9.3
6	55		1.0	21.7			21.1	55	8.6
Pre	50	9.9	0.6	25.0					

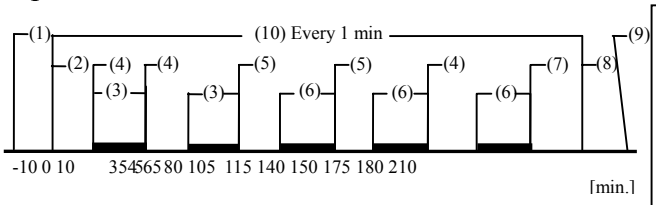
Subjects

A total of 15 healthy college-aged volunteers participated in the experiments. They were divided into groups composed of four subjects for each experiment. Considering the circadian rhythm, all the subjects took part in the experiments at the same time of a day and on the same days of a week during the whole experiment. Subjects had no knowledge about the purpose of the experiments and they were paid for their participation.

Experimental Procedure

Three-hour exposure periods started after subjects were seated quietly in the preparation room for 30 min. Experimental procedure is shown in Figure 2. Subjects performed simulated office works of 20-min addition task, twice and 25-min text typing, three times. During the 10-min interval between each task, subjects voted on the questionnaire and had a rest. The questionnaire consisted of questions related to general sensation (thermal sensation, comfort sensation, thermal acceptability, humidity sensation, humidity acceptability and sweat sensation, perceived air quality, odour intensity), local sensation (humidity sensation and

comfort sensation of eyes, mouth, nose, the back of the hand, the palm of the hand and feet), the dryness or humidness sensation of body segments, and self-performance. BUT and skin moisture of left arm and left hand were recorded every 60 min. At the end of exposure, oral mucosa moisture and the static electrification were recorded. At the beginning and at the end of each experiment, subjects went outside to vote the perceived outdoor air quality, and then re-enter in the chamber. Air temperature, relative humidity, globe temperature, ventilation rate, skin temperature and water vapour pressure under clothing were measured every 1 min during the exposure. Air velocity and indoor air quality were recorded, before or after the experiments.



(1) Coming-in Chamber, Change Clothes, Weight, Questionnaires
(2) Start of the Experiment, Questionnaires, Skin Moisture, BUT, Earth
(3) Addition Task
(4) Subjective vote
(5) Questionnaires, Skin Moisture, BUT
(6) Text Typing
(7) Questionnaires, Skin Moisture, BUT, Electric Potential, Oral mucosa moisture
(8) Stepping-out Chamber, Weight, Change Clothes, Questionnaires
(9) Reenter, Questionnaires, End of the Experiment
(10) Environment Measure (Temperature, Humidity, Glove Temperature), Skin Temperature, water vapor pressure under clothing

Figure 2. Experimental procedure

RESULTS AND DISCUSSION

Environmental Measurement The measured environmental conditions are also shown in Table 1. The actual humidity was a little different from the target value, due to the accuracy of environmental control of the chamber. However, SET* was fairly constant. The names of experimental conditions will be presented as the actual measurement values in the paper. The average concentration of formaldehyde and toluene were lower than 100 and 260μg/m^3, respectively, defined as the upper limit of the guideline of Ministry of Health, Labour and Welfare in Japan.

Skin Moisture During the exposure, skin moisture of left arm and hand was measured using SKICON-200 (IBS production) every 60 min. Subjects were asked to keep exposing their left arms and hands to the environments during the exposure. Skin moisture of left arm measured at the end of exposure is shown in Figures 3-1 and 3-2. Figure 3-1 shows the values based on relative humidity, and Figure 3-2 on humidity ratio. Significant differences of skin moisture were observed from 37 to 41%RH in Figure 3-1. According to Figure 3-2, boundary was suggested between humidity ratios of 8.2–8.6g/kg. Skin moisture increased with relative humidity bellow the boundary; On the other hand, relative humidity had small effects on skin moisture above it.

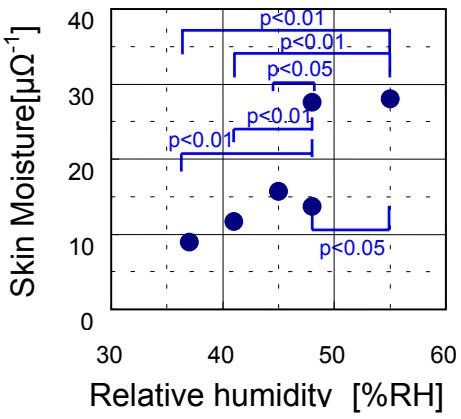


Figure 3-1 Skin moisture of left arm based on relative humidity.

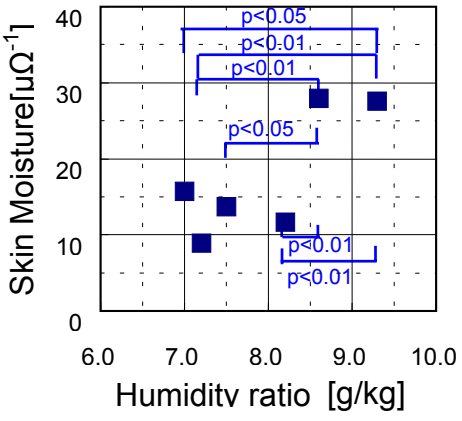


Figure 3-2 Skin moisture of left arm based on humidity ratio.

Oral Mucosa Moisture At the end of the exposure, Saxon tests (2000) were conducted. Subjects were asked to chew gauze at a rhythm of 1 time/s for 2 min. The weight difference of gauze before and after chewing was considered to be oral mucosa moisture. Oral mucosa moisture under different conditions is shown in Figure 4. Oral mucosa moisture under the 7.0 g/kg conditions was lower than that of other conditions. The difference between [37%RH/7.2 g/kg] and [45%RH/7.0 g/kg], [45%RH/7.0 g/kg] and [41%RH/8.2 g/kg], [48%RH/7.5 g/kg] and [48%RH/9.3 g/kg], and the difference between [45%RH/7.0 g/kg] and [55%RH/8.6 g/kg] was significant ($p < 0.01$). However, significant difference between the effects based on relative humidity and humidity ratio was not found.

Local Humidity Sensation As for general humidity sensation, namely, humidity sensation, humidity comfort and humidity acceptability, it showed that subjects felt slightly dry under low humidity within their tolerance level. The local humidity sensation of eyes, mouth and nose based on relative humidity and humidity ratio is shown in Figures 5-1 and 5-2, respectively. Under all the conditions, sensation of eye dryness was at the same as the level of nose, and declined with the rise of relative humidity and humidity ratio. The local humidity sensation of mouth was a little humid. No significant differences of local humidity sensation were found under all the conditions. Figure 6 shows the relationship between oral mucasa moisture and local humidity sensation of mouth. Oral mucasa moisture changed from about 0.0–8.0 g, but the difference of local dryness sensation of mouth was small. As for the relationship between BUT and local dryness sensation of eyes, the same tendency in which BUT changed widely, while the dryness sensation of eyes fluctuated little. No correlation was found between the physiological reaction and the psychological votes of subjects under narrow humidity ranges of these experiments.

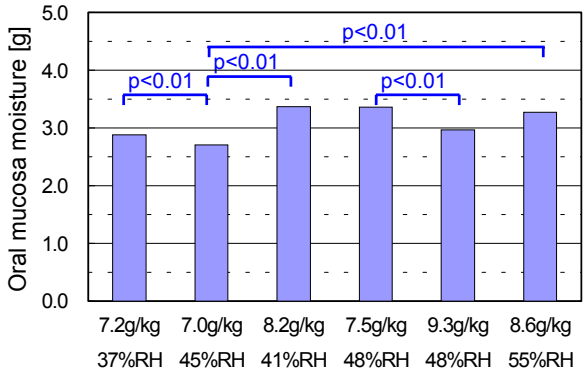


Figure 4 Oral mucosa moisture.

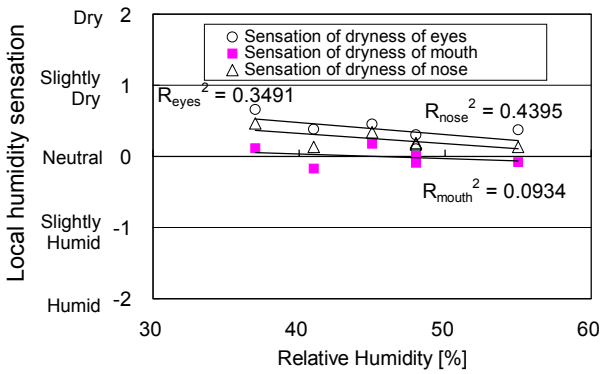


Figure 5-1 Local humidity sensation based on relative humidity.

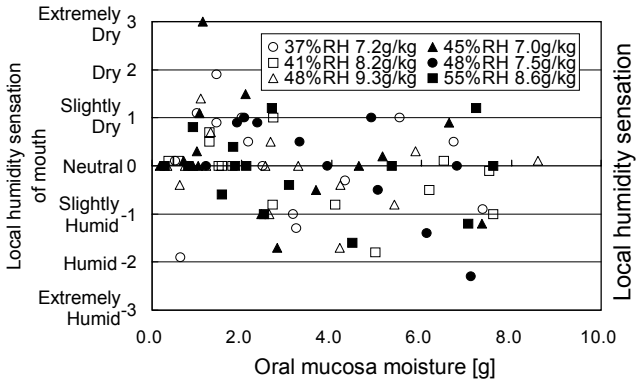


Figure 6 The relationship between oral mucosa moisture and local humidity sensation of mouth.

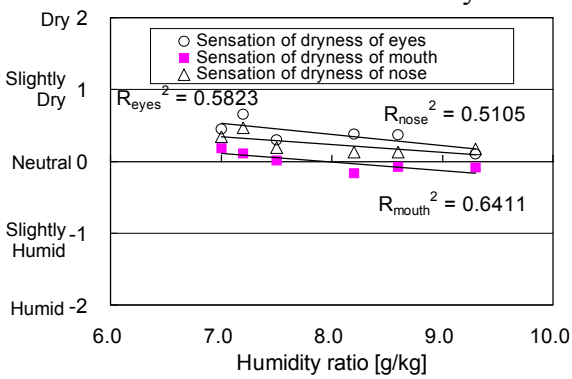


Figure 5-2 Local humidity sensation based on humidity ratio.

Perceived Indoor Air Quality There was little difference of votes of perceived indoor air quality under all the relative humidity or humidity ratio conditions. There were also fewer ranges of votes during the exposure. The votes of odour intensity during the whole experiment are shown in Figure 7. Subjects would get used to the odour after nearly 10 min although the concentration of formaldehyde and toluene was below the guideline in these experiments. Prominent difference between every relative humidity and humidity ratio conditions was not found.

Performance 'Addition task' was a 20-min calculation task, of two-digit numbers displayed on a computer. Computer showed the problems randomly. Answering speed, correct answer speed and percentage of correct answers were calculated. Figure 8 shows the averages of answering speed for all the subjects. No significant difference was found under all the humidity conditions. As for correct answer speed and its percentage, the same conclusions were obtained. Subjects also conducted English text-inputting tasks on a computer during the experiments. Small difference of typing speed was confirmed under all the conditions. The effects of humidity on task performance under the humidity range from 37 to 55%RH or from 7.0 to 9.3g/kg were insignificant.

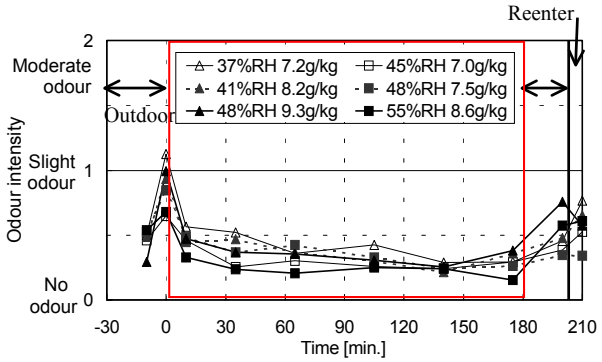


Figure 7 Odour intensity.

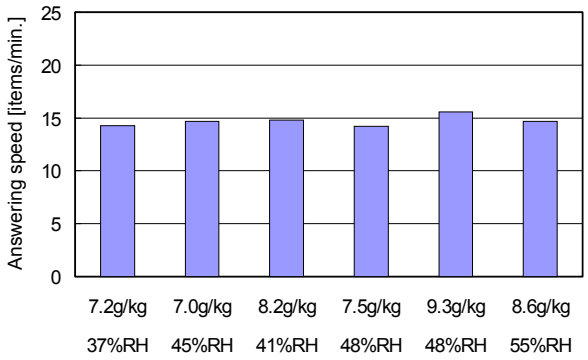


Figure 8 Answering speed.

Subjective Symptoms of Fatigue To estimate the feeling of fatigue, subjects filled in the 'Evaluation sheets of Subjective Symptoms of Fatigue' which is used in the field of labour and ergonomics science suggested by the working group for occupational fatigue of the Japan Society for Occupational Health. It consists of 30 items, which are divided into three categories of 10 items: category-I consisting of questions of 'drowsiness and dullness', category-II consisting of 'difficulty in concentration' and category-III consisting of 'physical symptoms' (Yoshitake, 1973). Figure 9 shows the rate of complaints of all the subjects at the beginning and at the end of the exposure. At the end of the exposure, rate of complaints was inclined under most of conditions. Under the conditions of [37%RH/7.2 g/kg], the difference of rate of complaints at the beginning and at the end of the exposure was clearly observed. On the other hand, under the conditions of [55%RH/8.6 g/kg] rates of complains at the end of the exposure minute were lower than those at the beginning. It was considered that under the environments where humidity ratio is above 8.6 g/kg, rates of complain of feeling fatigue are higher at first and declining with the time.

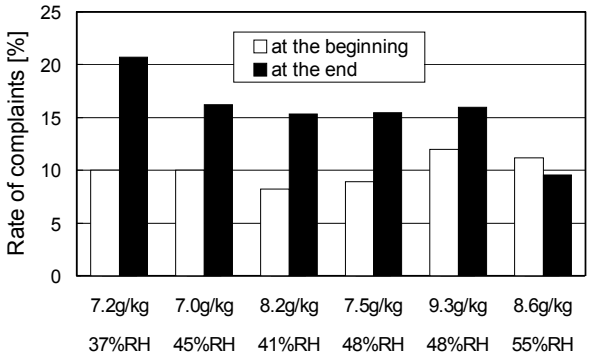


Figure 9 Total rate of complains.

CONCLUSIONS

Subjective experiments were conducted to investigate the effects of relative humidity or humidity ratio on the occupants' comfort and health. Fifteen college-aged subjects were exposed for 180 min under six humidity conditions at SET* = 25.2°C. As for general humidity sensation, subjects felt slightly dry under low humidity within their tolerance level. A boundary was suggested between humidity ratios of 8.2–8.6g/kg, below which Skin moisture increased with relative humidity. On the other hand, relative humidity had small effects on skin moisture above the boundary**.** Oral mucosa moisture under the 7.0 g/kg conditions was lower than that of other conditions. Under all the conditions, sensation of eye dryness was at the same level of nose, and it was declined with the rise of relative humidity and humidity ratio. The local humidity sensation of mouth was a little humid. Poor correlation was found between the physiological reaction and the psychology votes of subjects under the humidity ranges of this experiment. Though the effects of different humidity conditions (37–55%RH) on performance were small, subjects complained more of being fatigued under low humidity.

ACKNOWLEDGMENTS

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