EFFECTS OF EXTREMELY LOW HUMIDITY ON COMFORT AND FATIGUE OF JAPANESE OCCUPANTS

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ABSTRACT

Subjective experiments were carried out in a climate chamber using Japanese subjects, in order to evaluate human comfort at very low humidity. Two levels of absolute humidity were set. Three air temperature conditions for each absolute humidity level were examined. People were exposed in a chamber for 90 minutes with sedentary activity.

Subjective break up time got significantly shorter at extremely low absolute humidity. Air temperature had great impact on subjective general humidity sensation under the conditions set for this experiment. General dryness sensation at low absolute humidity was significantly greater than that at high absolute humidity with same air temperature. Subjects felt their eyes were dryer at low air temperature at the same moisture content in air. In case of the constant air temperature, low absolute humidity caused greater eye dryness sensation. Subjective humidity discomfort of females was greater than male. Very low humidity air dry up the human mucous membrane. Half of subjects perceived their palm of hand as wetted segment even at extremely low humidity. They could feel more tired at low humidity under the cool and thermally neutral condition, while they complained more at high humidity in hot environment. It was found that females tended to be more tired than males even under the same condition.

KEYWORDS

Extremely Low Humidity, Comfort, Fatigue, Subjective Experiment

INTRODUCTION

In Japan, the “Law for Maintenance of Sanitation in Buildings (1970)” is applied to offices whose total floor areas exceed 3,000 m^2. It states that the relative humidity in an office space should be kept between 40%RH and 70%RH. The ASHRAE Standard 55-92 (1992) prescribed a lower boundary humidity of 4.5 g/kg(DA) which was equivalent to 30%RH at 20.5°C. This standard was revised as the ASHRAE Standard 55-2004 (2004), which does not specify a minimum humidity level. The ASHRAE Standard 62-2001 (2001) recommends the relative humidity of 30%RH -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 create a thermal environment with low humidity even during summer using cold air distribution systems or desiccant dehumidifiers in many buildings. Further studies on the effects of low humidity on occupants’ comfort in other seasons are needed, as well as in winter.

The previous subjective experiment at 5%RH to 35%RH using Danish people reports that negative impacts on their tear film and blink rate were observed at below 15%RH, though the subjective discomfort was very mild even at 5%RH (Wyon et al. 2006). Tsutsumi et al. (2002, 2004, 2007) have reported the effects of low humidity on subjective comfort and productivity in summer through the various subjective experiments using Japanese subjects. As the result, negative effects of humidity

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were not found in the thermally neutral air even at 30%RH, which is below the lower boundary of humidity mentioned in Japanese law under a steady state in summer. However, the conditions examined in this series of experiments mentioned above, were between 30%RH and 70%RH. The studies on Japanese comfort and fatigue in the very dry air, especially below 15%RH, has been required.

This paper reports the subjective experiment conducted in a climate chamber for the purpose of evaluating comfort and fatigue of Japanese subjects at extremely low humidity.

METHOD OF SUBJECTIVE EXPERIMENT

Experimental design

Subjective experiments were carried out to evaluate the human comfort and fatigue in extremely low humidity air. A total of 16 Japanese adults of both gender, 8 males and 8 females, aged 20's-60's, were used as subjects. 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. The experimental conditions are listed in Table 1. Two levels of absolute humidity were set, 2.0g/kg(DA) and 10.0g/kg(DA). For each absolute humidity level, 3 air temperatures, 20.0, 25.0 and 30.0 °C, were examined. Mean radiant temperature (MRT) was estimated to be equivalent to air temperature. Air velocity was still for all conditions.

Table 1. Experimental conditions

	Absolute Humidity [g/kg(DA)]	Air Temperature =MRT [°C]	Relative Humidity [%RH]	Air Velocity
Low_20	2.0	20.0	13	still
Low_25		25.0	10	
Low_30		30.0	8	
High_20	10.0	20.0	68	
High_25		25.0	50	
High_30		30.0	38	

As shown in Figure 1, subjects were exposed in a climate chamber for 90 minutes, where a desiccant dehumidifier was equipped so that extremely low humidity air could be created. During the exposure time, subjects sat on the sofa and watched TV programs simulating the daily life at home. Subjects wore glasses or contact lenses during the exposure time if they uses them in their daily life. Subjective sensations, symptoms related to fatigue, and their self-performance were reported on the questionnaire using the visual analogue scale 5 times while they stayed in a chamber.

Skin moisture on subject's left forearm was recorded with Moisture checker (Scalar). Moisture checker measured capacitance of the skin (Agner 1992). Subjects kept their left forearm exposed to the air in the chamber during the 90-minute experiment. Subjects also measured their interval time between each blink by themselves using a stopwatch as Break up time (BUT) (Wyon and Wyon 1987).

People could control their clothing ensembles provided by the experimenter to keep their thermal sensation as neutral as possible. They were not allowed to eat or drink something and use eye drops during the exposure.

Air temperature, relative humidity, globe temperature during the experiments were logged every 10 second. Air velocity was measured before and after the exposure.

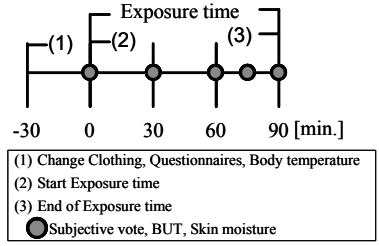

Figure 1. Experimental procedure.

Statistical analysis

Data at the end of 90-minute exposure were analysed as that obtained under steady state with Non-parametric statistical analysis method (Siegel 1984). Friedman nonparametric analysis was used for comparison among 3 conditions at the constant absolute humidity. The Wilcoxon Matched-Pairs Signed Ranks test was administered between each condition as a post-hoc test. This test was also used for the comparison between 2 absolute humidities at the same air temperature. Mann-Whitney U test was used for the comparison between male and female under the same condition. The p-values mentioned in the next section represent the levels of significance.

RESULTS AND DISCUSSION

Physiological reactions

Skin moisture:

Skin moisture is one of the physiological responses that could be affected by humidity and would cause the subjective dryness sensation and discomfort. Figure 2 shows the skin moisture measured on the left forearm of subjects at the end of exposure time. No significant difference was observed among 3 conditions with 2.0g/kg(DA). Clear direction was not found among conditions at 10.0g/kg(DA), although significant difference was gotten ($p<0.04$). Skin moisture on left forearm at low absolute humidity was significantly lower than in high absolute humidity air at the same air temperature ($p<0.02$). It is concluded that absolute humidity has great impact on subject's skin moisture although air temperature effects on it was moderate.

Break up Time (BUT):

Break up Time (BUT) of precorneal film is one of the physiological reactions that might affect the subjective eye comfort. During the exposure time, the subjects measured their interval time between each blink by themselves using a stopwatch. Figure 3 presents BUT measured after 90-minute exposure. Although the Friedman nonparametric analysis revealed no significant difference among 3 conditions, BUT at 20.0 °C was shorter than that at other conditions for both absolute humidity levels. The Wilcoxon Matched-Pairs Signed Ranks test reported that BUT at 25.0°C and 30.0 °C with 2.0g/kg(DA) was significantly shorter than at 10.0g/kg(DA) at the same temperature ($p<0.04$). Shorter BUT was observed under Low_20 condition than High_20 condition, although no statistically significant difference was seen. It is found that air temperature did not affect their BUT in case of keeping the constant absolute humidity. On the other hand, subjective BUT got significantly shorter at extremely low absolute humidity.

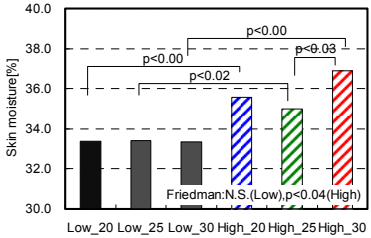

Figure 2. Skin moisture at the end of exposure

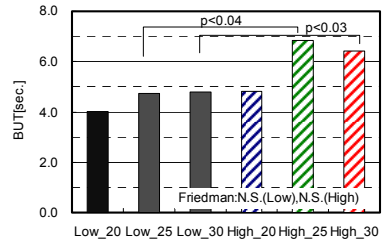

Figure 3. BUT.

Psychological reactions

Thermal sensation:

Thermal sensation vote at the end of the exposure time is shown in Figure 4. In both absolute humidity air, the Friedman nonparametric analysis revealed significant difference among 3 conditions ($p<0.00$). On the other hand, pair-wise comparison between low absolute humidity and high absolute humidity condition at the same air temperature did not found any significant difference. Subjective thermal sensation was associated with air temperature, while the effect of humidity was moderate under the conditions set for this research.

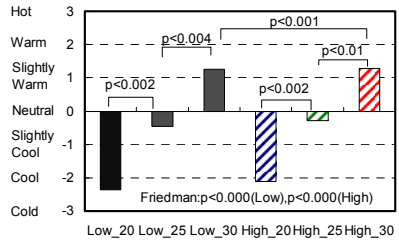

Figure 4. Thermal sensation vote

General humidity sensation:

The last humidity sensation vote is presented in Figure 5. General dryness sensation tended to be higher at low air temperature among 3 conditions with 2.0g/kg(DA) of absolute humidity ($p<0.1$). Friedman nonparametric analysis revealed statistically significant difference among 3 conditions in high absolute humidity air ($p<0.005$). Subjects felt the air was significantly dryer at low air temperature than at high air temperature at constant moisture content in air. Air temperature had great impact on subjective general humidity sensation under the conditions set for this experiment. According to the pair-wise comparison between 2 levels of absolute humidity at the same air temperature, it was found that general dryness sensation at low absolute humidity was significantly higher than that at high absolute humidity ($p<0.03$).

Figure 6 presents the general humidity sensation rated by males and females. No significant difference between males and females was found in general humidity sensation for all conditions.

Figure 7 displays subjective humidity comfort sensation rated using the same scale as comfort sensation. There was no significant difference among 3 conditions in low absolute humidity air.

Significant difference was occurred in high absolute humidity air ($p<0.04$). According to the Wilcoxon Matched-Pairs Signed Ranks test, greater discomfort was observed at 30.0 °C in high absolute humidity air than other conditions. Subjects reported greater discomfort in low absolute humidity air than high absolute humidity at 20.0 °C and 25.0 °C, while opposite result was found at 30.0 °C.

Humidity comfort sensation rated by males and females is shown in Figure 8. According to the comparison between males and females, females subjects reported significantly greater humidity discomfort at 20.0°C and 30.0°C in low absolute humidity air and at 25.0°C in high absolute humidity air ($p<0.04$). Humidity discomfort rated by female tended to be greater than males under the condition with 30.0 °C at high absolute humidity ($p<0.07$). Females rated greater humidity discomfort than males under the other condition, while no significant difference was found. This results clearly demonstrates that females felt greater discomfort due to indoor humidity than males.

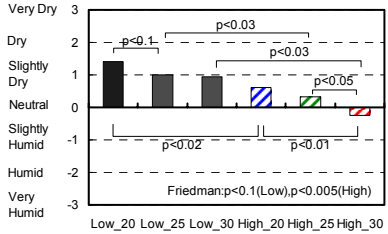

Figure 5. General humidity sensation vote

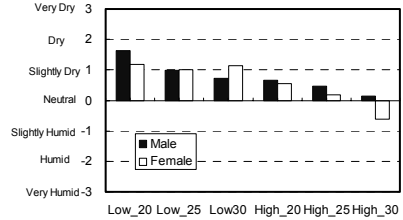

Figure 6. General humidity sensation vote rated by male and female

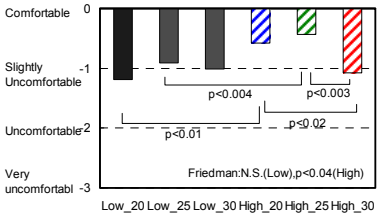

Figure 7. Humidity comfort sensation

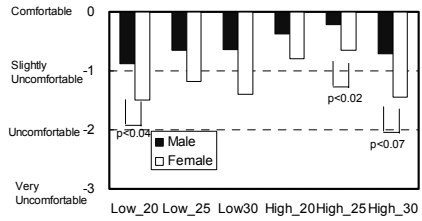

Figure 8. Humidity comfort sensation rated by male and female

Eye dryness sensation:

Subjects rated their sensation of eye dryness using the same scale as general humidity sensation. Figure 9 presents subjective sensation of eye dryness at the end of exposure time. Greater dryness sensation of eyes was seen at low air temperature than at high air temperature, while no significant difference was found among 3 conditions for both absolute humidity levels. The Wilcoxon Matched-Pairs Signed Ranks test between 2 absolute humidity conditions reveals significantly greater eye dryness sensation under low absolute humidity condition than high humidity condition at the same air temperature at the range from 20.0°C to 30.0°C. It is concluded that subjects felt their eyes were dryer at low air temperature, when keeping the same moisture content in air. In case of the constant air temperature, low absolute humidity caused greater eye dryness sensation.

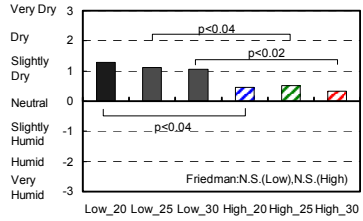

Figure 9.Sensation of eye dryness

Body segments subjects feel dry/ wet:

Subjects were asked to report their body segments which they felt dry or wet. Figures 10 and 11 display the number of people who reported each body part to be wet after 90-minute exposure, and Figures 12 and 13 to be dry. As shown in Figures 10 and 11, more segments were felt to be dry under the low absolute humidity condition than under high absolute humidity condition. More than 6 subjects felt their eyes, nose and mouth were dry at low absolute humidity. Even in the air with 10.0g/kg(DA), eyes, nose and mouth were rated as the parts where they felt dry. This result clearly demonstrated that very low humidity air dry up the human mucous membrane and subjects perceived it as dryness sensation.

As for the segments subjects perceived to be wet, subjects rated their palm of hand more than other segments for both absolute humidity conditions. More subjects felt their palm of hand were wet at 25.0°C and 30.0°C than at 20.0°C for both absolute humidities. Half of subjects reported their palm of hand as wetted segment even at 25.0°C/10%RH and 30.0°C/8%RH.

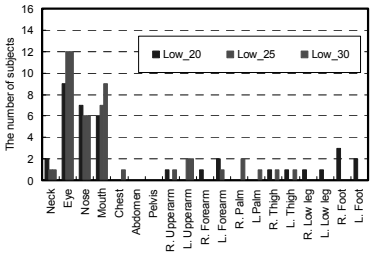

Figure 10. Body segment subjects felt “dry” at low absolute humidity (2.0g/kg(DA))

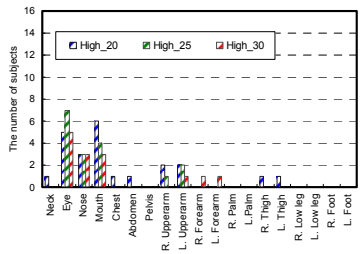

Figure 11. Body segment subjects felt “dry” at high absolute humidity (10.0g/kg(DA))

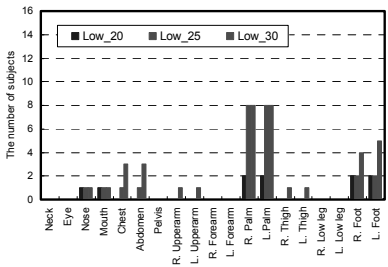

Figure 12. Body segment subjects felt “wet” at low absolute humidity (2.0g/kg(DA))

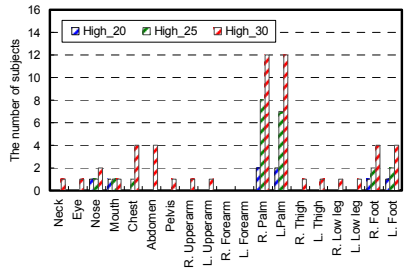

Figure 13. Body segment subjects felt “wet” at high absolute humidity (10.0g/kg(DA))

Fatigue

Subjects were asked to assess their general fatigue. A questionnaire proposed by the "Working Group for Occupational Fatigue, Japan Society for Occupational Health" was used to evaluate their fatigue (Yoshitake 1973). The questionnaire is composed of 3 groups, category I, category II and category III. "Category I" indicates drowsiness and dullness in subjects, "Category II" is about difficulty in concentration, and "Category III" is to do with physical discomfort. Each category has 10 symptoms related to subjective fatigue as listed in Table 2. Subjects marked "O" if they had the given symptoms, and marked "X" if they did not. Ratio of complaints was calculated for each category using the equation below:

$$Rate\ of\ complaints = \frac{Total\ number\ of\ complaints (= Total\ number\ of\ "O")}{(The\ number\ of\ symptoms) \times (Total\ number\ of\ subjects\ who\ used\ a\ questionnaire)} \times 100(\%)$$

As shown in Figure 14, higher air temperature at 10.0g/kg(DA) of absolute humidity caused higher ratio of complaints. In pair-wise comparison between high absolute humidity conditions and low absolute humidity condition with the same temperature, it was observed that the ratio of complaints at 2.0g/kg(DA) was higher at 20.0 and 25.0°C. On the other hand, people felt more tired at 30.0°C with high absolute humidity than that with low absolute humidity. It is concluded that people could feel more tired at low humidity under the cool and thermally neutral condition, while they complained more at high humidity in hot environment.

Table 2. Symptoms related to the general fatigue

	Category I Drowsiness and Dullness	**Category II** Difficulty in Concentrating	**Category III** Physical Discomfort
1	Feel heavy in the head	Feel difficult in thinking	Have a headache
2	Get tired through the whole body	Become weary of talking	Feel stiff in the shoulders
3	Get tired in the legs	Become nervous	Feel a pain in the back
4	Take a yawn	Unable to concentrate	Feel difficulty in breathing
5	Feel the brain hot or muddled	Unable to take interest in things	Feel thirsty
6	Become drowsy	Become apt to forget things	Have a husky voice
7	Feel eye strain	Lack in self-confidence	Have dizziness
8	Become rigid or clumsy in motion	Anxious about things	Have a spasm on the eyelids
9	Feel unsteady while standing	Unable to straighten up in a posture	Have a tremor in the limbs
10	Want to lie down	Lack patience	Feel ill

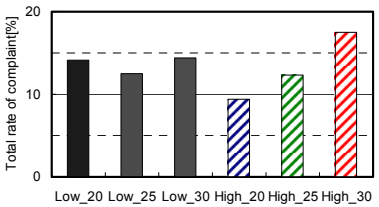

Figure 14. Total rate of complaint related to general fatigue

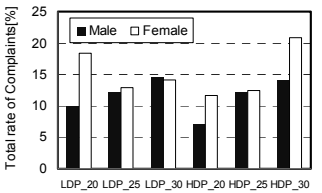

Figure 15. Total rate of complaint related to general fatigue reported by male and female

Figure 15 illustrates the total rate of complaint reported by males and females. Total rate of complaints of females was higher than that of males under the conditions except for 30.0°C in low absolute humidity air. It is concluded that females possibly feel more tired than males even under the same condition.

CONCLUSION

Subjective experiments were carried out in a climate chamber using 16 Japanese subjects of both genders, in order to evaluate human comfort at very low humidity. Two levels of absolute humidity were set. Three conditions for each absolute humidity were examined. People were exposed in a chamber for 90 minutes. Absolute humidity has great impact on subject's skin moisture although air temperature effects on it were moderate.

Air temperature did not affect their BUT in case of keeping the constant absolute humidity. On the other hand, subjective BUT got significantly shorter at extremely low absolute humidity. Air temperature had great impact on subjective general humidity sensation under the conditions set for this experiment. General dryness sensation at low absolute humidity was significantly higher than that at high absolute humidity with same air temperature.

Subjects felt their eyes were dryer at low air temperature, when keeping the same moisture content in air. In case of the constant air temperature, low absolute humidity caused greater eye dryness sensation. By comparison between males and females, subjective humidity discomfort of females was greater than male, though no significant difference was observed in general humidity sensation.

Very low humidity air dry up the human mucous membrane and subjects perceived it as dryness sensation. Half of subjects perceived their palm of hand as wetted segment even at 25.0°C/10%RH and 30.0°C/8%RH.

According to assessment of subjective fatigue, they could feel more tired at low humidity under the cool and thermally neutral condition, while they complained more at high humidity in hot environment. It was found that females tended to be more tired than males even under the same condition.

ACKNOWLEDGEMENT

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