Evaluation of Comfort and Fatigue of Japanese Subjects in Extremely Low Humidity Air

Hitomi Tsutsumi¹, Yoshitaka Hoda¹, Hayato Ohashi¹, Yuta Ezaki¹, Shin-ichi Tanabe¹, Junkichi Harigaya¹, and Toshihiko Ishizawa²

¹Department of Architecture, Waseda University, Japan
²Shin Nippon Air Technologies Co., Ltd., Japan

Corresponding email: tsutsumi@tanabe.arch.waseda.ac.jp

SUMMARY

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, 2.0 g/kg (DA) and 10.0 g/kg (DA). Three air temperature conditions with absolute humidity of 2.0 g/kg (DA), 20.0°C/13%RH, 25.0°C/10%RH and 30.0°C/8%RH, and 3 conditions with 10.0 g/kg (DA), 20.0°C/68%RH, 25.0°C/50%RH, 30.0°C/38%RH, were examined. People were exposed in a chamber for 90 minutes with sedentary activity. Subjects rated their sensations and subjective fatigue on the questionnaires during the exposure time. Skin moisture was measured on subjective left forearm by means of measuring capacitance of the skin. Break up time (BUT) was measured by subjects with a stopwatch.

Absolute humidity has great impact on subject’s skin moisture although air temperature effects on it were moderate. Subjective BUT got significantly shorter at extremely low absolute humidity. It was found that general dryness sensation at low absolute humidity was significantly higher than that at high absolute humidity. 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. Very low humidity air dry up the human mucous membrane and subjects perceived it as dryness sensation. Half of subjects reported their palm of hand as wetted segment even at 25.0°C/10%RH and 30.0°C/8%RH. Subjects felt more tired at very low absolute humidity under the cool and thermally neutral condition, while they complained more at high humidity in hot environment.

INTRODUCTION

In Japan, the “Law for Maintenance of Sanitation in Buildings [1]” is applied to offices whose total floor areas exceed 3,000 m². It states that the relative humidity in an office space should be kept between 40%RH 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%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 [5] 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.

Tsutsumi et al. [6][7][8] 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 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.

**METHODS**

**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, 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.

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

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. Subjective sensations, symptoms related to fatigue and visual 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 [9]. 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) [10].

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.](image)

**Statistical Analysis**
Data at the end of 90-minute exposure were analysed as that obtained under steady state with Non-parametric statistical analysis method [11]. 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. 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](image)

**Psychological Reactions**

Subjects rated their general thermal sensation, comfort sensation, humidity sensation, eye dryness and so on during the exposure. A part of rating scales is illustrated in Figure 4. The scales were given as visual analogue scales. Subjects were allowed to rate their sensation either just on the number or between the numbers on the scales.

![Figure 4. A part of rating scales](image)

**Thermal sensation:**

Thermal sensation vote at the end of the exposure time is shown in Figure 5. 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.
**General humidity sensation:**
The last humidity sensation vote is presented in Figure 6. 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 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 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.

**Eye dryness sensation:**
Subjects rated their sensation of eye dryness using the same scale as general humidity sensation. Figure 8 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.

**Body segments subjects feel dry/wet:**
Subjects were asked to report their body segments which they felt dry or wet. Figures 9 and 10 display the number of people who reported each body part to be humid after 90-minute exposure, and Figures 11 and 12 to be dry. As shown in Figures 9 and 10, more segments were felt to be dry under the low absolute condition than under high absolute 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 compared with other parts. 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 9](image9.png) **Figure 9.** Body segment subjects felt “dry” at low absolute humidity.

![Figure 10](image10.png) **Figure 10.** Body segment subjects felt “dry” at high absolute humidity.

![Figure 11](image11.png) **Figure 11.** Body segment subjects felt “wet” at low absolute humidity.

![Figure 12](image12.png) **Figure 12.** Body segment subjects felt “wet” at high absolute humidity.

**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 [12]. 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:

\[
\text{Rate of complaints} = \frac{\text{Total number of complaints}(= \text{Total number of “O”})}{(\text{The number of symptoms}) \times (\text{Total number of subjects who used a questionnaire})} \times 100(\%)
\]

Higher air temperature in 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.

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

Figure 13. Total rate of complaint related to general fatigue.

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, 2.0 g/kg(DA) and 10.0 g/kg(DA). Three conditions with absolute humidity of 2.0g/kg(DA), 20.0°C/13%RH, 25.0°C/10%RH and 30.0°C/8%RH, and 3 air temperature conditions with 10.0g/kg(DA), 20.0°C/68%RH, 25.0°C/50%RH, 30.0°C/38%RH, were examined. People were exposed in a chamber for 90 minutes with sedentary activity.
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. 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. 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.

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.

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REFERENCES