Impact of Indoor Humidity, Local Air Velocity and Illuminance on Subjective Comfort, Performance and Fatigue

Yoshitaka Hoda\textsuperscript{1}, Hitomi Tsutsumi\textsuperscript{1}, Shin-ichi Tanabe\textsuperscript{1}, and Akiko Arishiro\textsuperscript{2}

\textsuperscript{1}Department of Architecture, Waseda University, Japan
\textsuperscript{2}Automobile R&D Center, Honda R&D, Co., Ltd. Japan

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

SUMMARY

A subjective experiment was conducted using 15 college-aged subjects of both genders in order to evaluate their physiological and psychological reactions, performance and fatigue under the different combinations of indoor humidity, local air velocity and illuminance. The five-hour exposure periods were divided into three sections of 1.5 hours by 10-minute breaks. During each section, subjects performed 3 times of 20-minute task. During the exposure time subjects rated their sensations, visual fatigue and general fatigue, and measured their break up time (BUT) and skin moisture after each task.

Higher rate of complaints related to visual fatigue was reported under the condition with local air velocity than without it at the same humidity. High humidity caused subjective low visual fatigue. Subjective BUT was shorter in the environment with local air velocity or at low humidity, where people rated greater eye dryness sensation. High illuminance caused no difference in occupants’ physiological and psychological reactions although correct answer rate was higher in environment with high illuminance.

INTRODUCTION

Tsutsumi et al. [1] [2] [3] conducted subjective experiments on the effects of low humidity on occupants’ comfort and productivity. As the result, occupants’ discomfort caused by dryness was not found in the thermally neutral condition at below 40%RH. On the other hand, visual data acquisition could be interfered at very low humidity. In the daily life, local air velocity and illuminance could cause occupants’ general dryness sensation and eye dryness, blink, and visual fatigue as well as indoor humidity. Wyon et al. [4] reported other environmental factor like air velocity and illuminance also cause eye and skin dryness as well as indoor humidity.

Present paper reports the subjective experiments carried out to evaluate their physiological and psychological reactions, performance and fatigue under the different combinations of indoor humidity, local air velocity and illuminance.

METHODS

Experimental design

A subjective experiment was conducted in a climate chamber using 15 college aged subjects, 7 males and 8 females, in order to evaluate their physiological and psychological reactions, performance and fatigue under the different combinations of indoor humidity, local air velocity and illuminance.

Experimental conditions:
The experimental conditions are listed in Table 1.
For all conditions, air temperature was kept at 25.0 °C. Two levels of humidity conditions, 30%RH and 70%RH, were set. For each humidity condition, two conditions of local air velocity to subject’s face with a small fan on the desk, with and without velocity of 1.0 m/s, were examined. A condition with high illuminance at 30%RH without local air velocity was also studied. Under the condition with high illuminance at 30%RH, vertical illuminance in front of PC screen on the desk of subject was about 1200 lx while under other four conditions it was 400-450 lx. Each subject wore the clothing ensembles that consisted of a long-sleeve shirt, short-sleeve T-shirt, trousers, socks and shoes. All subjects wore their own underwear. Clo value was measured to be 0.85clo by using a thermal manikin.

### Table 1. Experimental conditions.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Air Temperature (M=RT)</th>
<th>Relative Humidity</th>
<th>Local Air Velocity</th>
<th>Vertical Illuminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%RH</td>
<td>25.0°C</td>
<td>30%RH</td>
<td>Without</td>
<td>400-450lx</td>
</tr>
<tr>
<td>30%RH + Local Air Velocity (LV)</td>
<td>25.0°C</td>
<td>30%RH</td>
<td>With</td>
<td>1200lx</td>
</tr>
<tr>
<td>30%RH + High Illuminance (HI)</td>
<td>25.0°C</td>
<td>30%RH</td>
<td>Without</td>
<td>400-450lx</td>
</tr>
<tr>
<td>70%RH</td>
<td>25.0°C</td>
<td>70%RH</td>
<td>Without</td>
<td>400-450lx</td>
</tr>
<tr>
<td>70%RH + LV</td>
<td>25.0°C</td>
<td>70%RH</td>
<td>With</td>
<td>400-450lx</td>
</tr>
</tbody>
</table>

### Experimental procedure:
Figure 1 shows the experimental procedure. People were exposed in a climate chamber for 5 hours. The five-hour exposure periods were divided into three sections of 1.5 hours by 10-minute breaks. During each section, subjects performed 20-minute task three times: 1) Short-term memory task [5], 2) Vigilance task [5], 3) Visual recognition and reaction task. Subjects could only drink a bottle of water provided by the experimenters during the exposure time. During 10-minute break between sections, people were allowed to go out the climate chamber. Air temperature, relative humidity and globe temperature in the chamber were logged every minute. Air velocity before and after the exposure time was also recorded.

### Tasks:
During the exposure, subjects performed 3 types of task: 1) Short-term memory task [5], 2) Vigilance task [5], 3) Visual recognition and reaction task, as presented in Table 2. High visual data acquisition, quick judgments and response are needed for all tasks. Therefore, short Break up time (BUT) or visual fatigue due to the indoor environment could affect their performance. Subjective discomfort to the environment would also cause general fatigue that reduces their performance.

### Table 2. Detail of 3 tasks.

**Short-term memory task**
1. Total of six numbers were displayed every second.
2. One number to be judged were shown.
3. If the number was included in 6 numbers, subjects reacted as soon as possible. If not, they didn't. Time limit was 3 seconds.

**Vigilance task**
1. Total of 3 numbers were displayed every second.
2. When three different odd numbers were shown, subjects reacted as soon as possible. If not, they didn't. Time limit was 3 seconds.

**Visual recognition and reaction task**
1. For three seconds, ten characters that consist of numbers (1-9) and alphabets (a-z) were shown at random.
2. When an odd number appears, subject reacted as fast as possible. If not, they didn't.
**Statistical analysis**

Data obtained in the experiments were analyzed with Non-parametric statistical analysis method [6]. The Wilcoxon Matched-Pairs Signed Ranks test was administered between each condition. Indoor humidity effect was discussed in the pair-wise comparison between 30%RH and 70%RH, and between 30%RH+LV and 70%RH+LV. According to the comparison between 30%RH and 30%RH+LV, and between 70%RH and 70%RH+LV, local air velocity effect was reported. Pair wise test between 30%RH and 30%RH+HI reported the effect of indoor illuminance. P-values presented in the figures indicate the level of significance.

**RESULTS AND DISCUSSION**

**Physiological responses**

**Skin moisture**

Skin moisture was measured on a subject’s left forearm with “Skicon-200” (IBS Corp.). Skicon-200 adopts the high frequency impedance method [7]. As shown in the Figure 2, skin moisture after all tasks at 30%RH was lower than at 70%RH and at 30%RH+LV than 70%RH+LV (p<0.01). Low humidity caused their low skin moisture. No significant difference was observed between 30%RH and 30%RH+LV and between 70%RH and 70%RH+LV. Local air velocity did not have great impact on subjective skin moisture. No significant difference was observed between 30%RH and 30%RH+HI. The effect of illuminance was moderate in this experiment.

![Figure 2. Skin moisture.](image)

**Break up time (BUT)**

Break up Time (BUT) of precorneal film is one of the physiological reactions that might affect the subjective eye comfort [8]. During the exposure time, the subjects measured their interval time between each blink by themselves using a stopwatch as “BUT” after each task for this research. BUT recorded at the end of exposure was shown in Figure 3. BUT after all task under 30%RH+LV was significantly shorter than under 30%RH (p<0.02). Shorter BUT was observed under 70%RH+LV than 70%RH although no statistically significant difference was observed. It is found that BUT became shorter in the environment with local air velocity. There was significant difference in BUT after Visual recognition and reaction task between 30%RH+LV and 70%RH+LV (p<0.05). BUT measured after Short-term memory task and Vigilance task at 30%RH and at 30%RH+LV were shorter than 70%RH and 70%RH+LV respectively. Low humidity had the impact that makes subjective BUT gotten shorter. No statistically significant difference was observed between 30%RH and 30%RH+HI.
Figure 3. BUT measured at the end of each task.

Psychological reactions

General humidity sensation

Figure 4 presents the general humidity sensation rated by subjects after each task. Subjects tended to feel dryer after Short-term memory task and vigilance task under 30%RH+LV than that under 30%RH (p<0.1). While no significant difference was found, general dryness sensation under the condition with local air velocity was higher than under the condition without local air velocity at the same humidity. General dryness sensation tended to be higher at 30%RH+LV than 70%RH+LV after Vigilance task and the Visual recognition and reaction task (p<0.1). Subjects reported significantly higher dryness sensation at 30%RH than at 70%RH after the Visual recognition and reaction task (p<0.03). It is found that people perceived air to be dryer under low humidity condition. No significant difference was observed between 30%RH and 30%RH+HI. Difference of illuminance examined in this experiment did not have great impact on subjective general humidity sensation.

Figure 4. General humidity sensation.

Sensation of eye dryness

Eye dryness sensation vote after each task was shown in Figure 5. Eye dryness at 30%RH was significantly higher than at 70%RH after all tasks in pair-wise comparison (p<0.01). Subjects reported greater eye dryness at 30%RH+LV than 70%RH+LV after all tasks although no significant differences were gotten. It proved that indoor humidity has an impact on subjective eye dryness sensation. Statistically significant differences occurred between 70%RH and 70%RH+LV after all tasks, and between 30%RH and 30%RH+LV after the Short-term memory task and Vigilance task (p<0.04). People reported their eyes were dryer in the environment with local velocity than at the same humidity without velocity.
Since no significant difference was found between 30%RH and 30%RH+HI, it is concluded that the effect of illuminance on subjective sensation of eyes were not found in this experiment.

Figure 5. Sensation of eye dryness.

Sensation of eye comfort

As shown in Figure 6, there was no significant difference between 2 humidity levels for both of with and without local velocity. Subjective discomfort was significantly greater at 30%RH+LV than 30%RH after Short-term memory task and Vigilance task and at 70%RH+LV than 70%RH after Short-term memory task and Visual recognition and reaction task (p<0.04). People reported greater eye discomfort at 30%RH+LV than at 30%RH after Visual recognition and reaction task, and at 70%RH+LV than 70%RH after Vigilance task but these findings were not significant. This result demonstrated that subjects felt their eyes were more uncomfortable in the air with velocity. According to no significant difference between 30%RH and 30%RH+HI, illuminance did not affect subjective sensation of eye comfort.

Figure 6. Sensation of eye comfort.

Performance and fatigue

Correct answer rate

Figure 7 shows the correct answer rate of last task for each section. The correct answer rate indicates the ratio of correct answers to all questions during a 20-minute task. Correct answer rate of Vigilance task was above 90% for all conditions, while that of Short-term memory task was between 60 and 85%. It was found that Short-term memory task was the most difficult task and Vigilance the easiest. Same tendency of the correct answer rate under different conditions were obtained for all tasks. Correct answer rate at 30%RH+HI tended to be higher than at 30%RH for all tasks.(p<0.07)

No significant difference between 70%RH and 70%RH+LV were found. Correct answer rate of Short-term memory task at 30%RH+LV was significantly higher than at 30%RH (p<0.05) and that of Visual recognition and reaction task tended to be higher at 30%RH+LV than at
30%RH (p<0.06). This might be caused by the comfortable thermal environment at 30%RH with air velocity, where PMV (Predicted Mean Vote) was +0.72, between “0: neutral” and “+1: slightly warm”, at 30%RH and −0.1, near “0: neutral”, at 30%RH+LV. As for the effect of indoor humidity, correct answer rate of Short-term memory task at 30%RH tended to be lower than 70%RH (p<0.08). Higher rate of correct answer at 70%RH was found compared with that at 30%RH, nevertheless there was no statistically significant difference.

Figure 7. Correct answer rate of each task.

Figure 8 presents the relationship between subjective BUT and correct answer rate of the Short-term memory task and the Visual recognition and reaction task. Both figures demonstrated that longer BUT could cause higher correct answer rate. It is concluded that in case that the subjective BUT gets shorter due to indoor environment, subjective performance would become lower.

Figure 8. Relationship between BUT and correct answer rate.
(Left: Short-term memory task, Right: Visual recognition and reaction task)

General fatigue

Subjects were asked to assess their general fatigue [9]. The questionnaire is composed of 3 groups. Each category has 10 symptoms related to subjective fatigue. 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:

\[
\text{Rate of complaints [%]} = \frac{\text{Total number of complaints}}{\text{The number of symptoms} \times \text{The number of subjects who used a questionnaire}}
\]

Three patterns were suggested by comparing the rate of complaints for each category: I>III>II: I-dominant, I>II>III: II-dominant, and III>I>II: III-dominant. “I-dominant” indicates a general pattern of fatigue, “II-dominant” a typical pattern of fatigue for mental work or night work and “III-dominant” a typical pattern of fatigue for physical work.
Table 3 listed the rate of complaints. Total rate of complaints was about 10% for all conditions examined in this experiment. On the other hand, type of fatigue reported after Short-term memory task under 30%RH+LV, 30%RH+HI and 70%RH was I>II>III; II-dominant, while I>III>II was rated under any other condition. It is concluded that mental work load was greater during performing the Short-term memory task than any other task.

### Table 3. Rate of complaints related to fatigue.

<table>
<thead>
<tr>
<th>Task</th>
<th>Condition</th>
<th>Category I [%]</th>
<th>Category II [%]</th>
<th>Category III [%]</th>
<th>Type of fatigue</th>
<th>Total rate of Complaints [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-term memory task</td>
<td>30%RH</td>
<td>27.3</td>
<td>0.7</td>
<td>6.6</td>
<td>I-III-II</td>
<td>I-dominant 11.3</td>
</tr>
<tr>
<td></td>
<td>30%RH+LV</td>
<td>14.7</td>
<td>7.3</td>
<td>6.0</td>
<td>I-III-II</td>
<td>II-dominant 8.7</td>
</tr>
<tr>
<td></td>
<td>30%RH+HI</td>
<td>22.8</td>
<td>8.7</td>
<td>6.0</td>
<td>I-III-II</td>
<td>II-dominant 12.5</td>
</tr>
<tr>
<td></td>
<td>70%RH</td>
<td>21.3</td>
<td>7.3</td>
<td>6.0</td>
<td>I-III-II</td>
<td>II-dominant 11.6</td>
</tr>
<tr>
<td></td>
<td>70%RH+LV</td>
<td>15.3</td>
<td>4.7</td>
<td>7.3</td>
<td>I-III-II</td>
<td>I-dominant 8.1</td>
</tr>
<tr>
<td></td>
<td>30%RH</td>
<td>13.3</td>
<td>0.7</td>
<td>8.0</td>
<td>I-III-II</td>
<td>I-dominant 7.3</td>
</tr>
<tr>
<td></td>
<td>30%RH+LV</td>
<td>17.3</td>
<td>3.3</td>
<td>4.0</td>
<td>I-III-II</td>
<td>II-dominant 8.2</td>
</tr>
<tr>
<td></td>
<td>30%RH+HI</td>
<td>25.3</td>
<td>7.3</td>
<td>5.3</td>
<td>I-III-II</td>
<td>II-dominant 12.7</td>
</tr>
<tr>
<td></td>
<td>70%RH</td>
<td>9.3</td>
<td>2.0</td>
<td>4.2</td>
<td>I-III-II</td>
<td>I-dominant 7.3</td>
</tr>
<tr>
<td></td>
<td>70%RH+LV</td>
<td>18.0</td>
<td>6.0</td>
<td>8.0</td>
<td>I-III-II</td>
<td>I-dominant 10.7</td>
</tr>
<tr>
<td>Vigilance task</td>
<td>30%RH</td>
<td>14.0</td>
<td>3.3</td>
<td>7.3</td>
<td>I-III-II</td>
<td>I-dominant 8.2</td>
</tr>
<tr>
<td></td>
<td>30%RH+LV</td>
<td>16.7</td>
<td>3.3</td>
<td>5.3</td>
<td>I-III-II</td>
<td>I-dominant 8.4</td>
</tr>
<tr>
<td></td>
<td>30%RH+HI</td>
<td>15.3</td>
<td>2.7</td>
<td>5.3</td>
<td>I-III-II</td>
<td>I-dominant 7.8</td>
</tr>
<tr>
<td></td>
<td>70%RH</td>
<td>8.7</td>
<td>1.3</td>
<td>4.7</td>
<td>I-III-II</td>
<td>I-dominant 4.9</td>
</tr>
<tr>
<td></td>
<td>70%RH+LV</td>
<td>23.3</td>
<td>5.3</td>
<td>7.3</td>
<td>I-III-II</td>
<td>I-dominant 12.0</td>
</tr>
<tr>
<td>Visual recognition and reaction task</td>
<td>30%RH</td>
<td>14.0</td>
<td>3.3</td>
<td>7.3</td>
<td>I-III-II</td>
<td>I-dominant 8.2</td>
</tr>
<tr>
<td></td>
<td>30%RH+LV</td>
<td>16.7</td>
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<td></td>
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<td></td>
<td>70%RH</td>
<td>8.7</td>
<td>1.3</td>
<td>4.7</td>
<td>I-III-II</td>
<td>I-dominant 4.9</td>
</tr>
<tr>
<td></td>
<td>70%RH+LV</td>
<td>23.3</td>
<td>5.3</td>
<td>7.3</td>
<td>I-III-II</td>
<td>I-dominant 12.0</td>
</tr>
</tbody>
</table>

**Visual fatigue**

Subjects reported their visual fatigue on the questionnaire referred to Takahashi [10]. Twenty symptoms related to visual fatigue were shown on the questionnaire. Subjects marked “O” if they had the given symptoms, and marked “X” if they did not. Total rate of complaint related to visual fatigue was calculated by using the same method as equation mentioned in the session of general fatigue.

Figure 9 presents the visual fatigue rated at the end of each task. People complained more after all tasks in the environment with local air velocity compared with the condition without air velocity at same humidity. More complaints were reported at 30%RH than 70%RH after all tasks.

![Figure 9. Visual fatigue rated at the end of each task.](image)

**CONCLUSION**

A subjective experiment was conducted using 15 college-aged subjects of both genders in order to evaluate their physiological and psychological reactions, performance and fatigue under the different combinations of indoor humidity, local air velocity and illuminance. The five-hour exposure periods were divided into three sections of 1.5 hours by 10-minute breaks. During each section, subjects performed 3 times of 20-minute task.

Low humidity caused subjects’ low skin moisture and general dryness sensation. On the other hand, local air velocity did not have great impact on subjective skin moisture while general
dryness sensation under the condition with local velocity was higher than under the condition without local velocity at the same humidity. It is found that BUT became shorter and visual fatigue became greater in the environment with local air velocity and at low humidity. It proved that indoor humidity and local velocity has negative impact on subjective eye dryness sensation and visual fatigue, while only local velocity affects their sensation of eye comfort. Subjective mental work load was found to be greater during performing short term memory task than other tasks.

According to the results in their performance, it is concluded that if the subjective BUT gets shorter due to indoor environment, subjective performance would become lower. High illuminance caused no difference in occupants’ physiological and psychological reactions although correct answer rate was higher in environment with high illuminance.

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