NEW INDEX OF COMBINED EFFECT OF TEMPERATURE AND NOISE ON HUMAN COMFORT: SUMMER EXPERIMENTS ON HOT AMBIENT TEMPERATURE AND TRAFFIC NOISE

Nagano K¹, Horikoshi T²

¹Department of Industrial Design, Kyushu Institute of Design, Fukuoka 815-8540, Japan
²Department of Environmental Technology & Urban Planning, Graduate School of Engineering, Nagoya Institute of Technology, Nagoya 466-8555, Japan

Abstract

Twenty-nine male students were exposed to the combined twenty-five conditions of operative temperatures (27, 30, 33, 36, 39°C) and noise levels (46.8L_Aeq: air-conditioning noise, 59.2, 73.1, 80.0, 95.4L_Aeq: traffic noise). The subjects reported their sensation of temperature, sound and comfort for each experimental condition using the linear unipolar scales. The following results were obtained: the auditory condition affected significantly the thermal comfort and discomfort sensations as well as the noisy and quiet sensations, and thermal condition also affected the noisy and quiet sensations significantly. Both of temperature and noise affected obviously the universal comfort and discomfort sensations. These results provided the fact that there exist measurable interaction between the above-mentioned sensations affected with temperature and noise. Consequently, equi-comfort and equi-discomfort charts constituted with the operative temperature and L_Aeq as a new comfort index were proposed to quantitatively evaluate the combined effect of hot and noisy conditions based on the experiments' results. These charts can reasonably predict the human comfort and discomfort sensations from the given temperature and noise conditions within this experimental condition.

Key words: Combined effect, Temperature, Noise, Psychological response, Equi-comfort chart

Introduction

The purpose of this study is to propose a new comfort index for indication of the combined effect of heat and noise stress on the human state of mind. The several previous studies have been conducted on the combined effect of heat and noise on the human body (Viteles and Smith 1946; Poulton et al. 1974; Bell 1978; Grether et al. 1971, 1972; Schust et al. 1991), but few investigation of them are enough to find quantitative combined effect in hot and noisy conditions. It is important to quantitatively determine the combined effects of each environmental factor on the human responses in order to obtain in-situ evaluation of daily environment that the officers and the dwellers usually live in. For this purpose, this study investigates the quantitative relationship between each factor and the non-specific evaluation (i.e. the universal comfort and discomfort), because the evaluation method by means of the non-specific scale may be useful to find the synthesized evaluation of the combined environmental factors as Horie et al. (1985) have reported. Furthermore, this study simultaneously measures the individual sensation (e.g. hot, noisy, bright and so on) and the specific evaluation of each factor (i.e. the thermal comfort/discomfort, the auditory, and the like) so as to approach the human comfort state from the various aspects.
Material and methods

Subjects

The subjects were twenty-nine male students of Nagoya Institute of Technology in good health and with normal hearing, ranged in age between 19 and 37 (Mean (SD) = 22.1 (3.3)). All of them participated voluntarily in all the experimental conditions and were paid proper rewards for their participation. In the experimental chamber they wore only cotton undershorts at sedentary posture.

Experimental Conditions

The pre-test room was kept at 27°C for operative temperature that might give us thermally neutral feelings and 45.9L_{Aeq} under air-conditioning noise level. In the test room, five operative temperature levels (27, 30, 33, 36, 39°C) at each of five noise levels (46.8L_{Aeq}: air-conditioning noise; 59.2, 73.1, 80.0, 95.4L_{Aeq}: traffic noise) constituted twenty-five experimental conditions. Relative humidity and air velocity were approximately 30-70% and less than 0.15m/s, respectively, at the occupied zone in the test room and the pre-test room.

Experimental Facilities

The experimental program was conducted at the experimental chamber in Nagoya Institute of Technology. Fig.1 shows a floor plan of the experimental rooms. Two rooms were built by steel frames and polystyrene foams. Dimensions of the pre-test room on the left of the figure were 2,400mm by 2,700mm with a ceiling height of 2,400mm. Those of the test room on the right of the figure were 3,600mm wide, 3,000mm long and 2,400mm height. The interior surfaces of each room were covered by gray colored (N8.5) curtain. It was possible to separately control the air temperatures of each room by means of the packaged air-conditioner. Traffic noise has been recorded on the bridge over the highway in a Nagoya suburb and was presented using the digital audio tape recorder (SONY TCD-D10 PRO II). Noise levels were adjusted by the volume of the amplifier (AIWA S-A22).

Measurement

The ambient air temperatures and wet bulb temperatures in the pre-test and test rooms were measured by a ventilating psychrometer at 700mm high above the floor, and the globe temperature...
was measured by a globe thermometer. Along with these temperatures, the surface temperatures of the walls, floor and ceiling and the vertical distribution of air temperature were continuously measured and monitored by 0.3mm T-type thermocouples. Mean radiant temperatures for calculating the operative temperature (Winslow et al. 1937) were calculated using the surface temperatures of the walls, floor and ceiling and the angle factors between a person (as the 500mm-sized cube model (Horikoshi et al. 1978)) and each surface. As shown in Fig.2, twenty linear unipolar scales were adopted for the psychological measurements. Each Japanese term is located on the right side of the line that means the highest point and its negative term is appended to the left for the subjects' easy comprehension. The subjects were instructed to put a mark on the line of which the position described their feelings of the environment.

![Table of Japanese terms for sensory perceptions]

**Fig. 2** Form completed while the subjects is in the test room

<table>
<thead>
<tr>
<th>Pre-test room</th>
<th>Test room</th>
</tr>
</thead>
<tbody>
<tr>
<td>(27°C, 45.9L_{Aeq})</td>
<td>(27, 30, 33, 36, 39°C; 46.8 59.2, 73.1, 80.0, 95.4L_{Aeq})</td>
</tr>
<tr>
<td>30min.</td>
<td>2min. 1min. 2min. 7min.</td>
</tr>
<tr>
<td>Adaptation</td>
<td>Noise stimulus</td>
</tr>
<tr>
<td></td>
<td>Rating</td>
</tr>
<tr>
<td></td>
<td>1st set of ratings</td>
</tr>
<tr>
<td></td>
<td>2nd set of ratings</td>
</tr>
</tbody>
</table>

**Fig. 3** Experimental procedure
Procedure

The time schedule of the experiment is shown in Fig. 3. All experiments were conducted in the morning (9:00-12:30) or afternoon (13:30-19:00) from 14 June to 7 July 1998, but not during the hour after the breakfast or the hour after lunch, to ensure that the subjects’ metabolism was stable. After a half hour of thermal adaptation in the pre-test room, the subjects walked in the test room and sat on the chair. They reported the impression of the exposed environment on the ballot after presenting the noise stimuli during 2 minutes. After 7 minutes, they repeated the ratings for the same exposed condition. All subjects were exposed to only one thermal condition a day for preventing the subjects from excessive physical and mental stress. In this paper the second set of ratings, which were conducted on more steady state, was analyzed.

ANOVA for two-factor model of temperature and noise were used for each sensation vote in order to investigate the effect of each environmental factor and of the interaction statistically.
noise were used for each sensation votes in order to investigate the effect of each environmental factor and of the interaction statistically.

**Results**

Fig. 4 and Fig. 5 show the relationship between the operative temperature and the mean values of thermal sensation votes. With rising the operative temperature, the hot and thermal discomfort sensation votes rose to higher level, and the cold and thermal comfort sensation votes went down to lower level. The hot and cold sensations had little relation with noise level, but thermal comfort and discomfort votes slightly became lower and higher respectively as the noise levels increased. For the hot sensation votes, ANOVA indicated that these votes were significantly affected with the main effect of temperature (F=114.51, p<0.01), but not with the main effect of noise (F=1.30, n.s.) and with the interaction of them (F=0.63, n.s.). The cold sensation votes were significantly affected with the main effect of temperature (F=8.52, p<0.01), but not with the main effect of noise (F=0.69, n.s.) and with the interaction of them (F=0.93, n.s.). The thermal comfort sensation votes were not only affected significantly with the main effect of temperature (F=65.24, p<0.01) but of noise (F=3.79, p<0.01). The thermal discomfort sensation votes were also affected significantly with the main effect of temperature (F=85.72, p<0.01) and of noise (F=6.09, p<0.01).

Fig. 6 and Fig. 7 show the relationship between the noise level and the mean values of auditory sensation votes. As the noise level increased, the subjects voted noisier and vice versa on the quiet sensation votes, the subjects reported less auditory comfortable and more auditory uncomfortable, with little respect to the operative temperature. The noisy sensation votes were not only affected significantly with the main effect of noise (F=170.55, p<0.01), but also with the main effect of temperature (F=2.66, p<0.05) and with the interaction (F=2.87, p<0.01). The quiet sensation votes were also significantly affected with the main effect of noise (F=178.98, p<0.01), with the main effect of temperature (F=3.25, p<0.05) and with the interaction (F=2.20, p<0.01). As for the auditory comfort sensation votes, ANOVA indicated that the main effect of noise significantly affected them (F=68.08, p<0.01) and both of the main effect of temperature (F=1.91, p=0.11) and the interaction (F=1.44, p=0.12) affected them insignificantly. The auditory discomfort sensation votes were affected with both of the main effect of noise (F=103.57, p<0.01) and with the interaction (F=2.14, p<0.01) significantly,
thermic feeling (SETF). Further study should be conducted, but with the main effect of temperature \((F=1.99, p=0.10)\) insignificantly.

Fig. 8 and Fig. 9 show the relationship between the operative temperature and the mean values of universal comfort and discomfort sensation votes, respectively. With raising the operative temperatures, and with increasing noise levels, the universal comfort sensation votes changed to lower level and the universal discomfort sensation votes rose to higher level.

**Discussion**

According to Fig. 4 and the results of the statistical analysis on the hot and the cold sensation votes, the noise level had little effects to both of the sensations. Schust et al. (1991) and Mochizuki et al. (1998) have found no effects of noise on the thermal sensation. And Fanger et al. (1977) reported that the noise level didn’t influence the ambient temperature preferred by the subjects or the skin and the rectal temperature. The results of this paper support the findings of these previous papers. However, thermal comfort and discomfort sensation votes were affected with the noise level slightly but significantly as shown in the results of Fig. 5 and ANOVAs. And Borsky et al. (1993) have shown that the noise has significantly caused the increase of the subjective evaluation of thermic feeling (SETF). Further study should be conducted, but the auditory factor had better be considered in the study about the thermal effect on the human state of mind, especially when it is necessary to investigate the slight difference and fluctuation of the psychological responses.

As the results of Fig. 6, Fig. 7 and ANOVAs, the noisy and quiet sensation votes were significantly influenced by the operative temperature. The operative temperature had also the slight effects on auditory comfort and discomfort sensation votes. The thermal environment should be taken into account in the acoustical study as the case.

As shown in Fig. 8 and Fig. 9, it is obvious that the combined effect of temperature and noise is represented in the universal comfort and discomfort sensation. These scales can simultaneously evaluate
the thermal and auditory environment. Fig. 10 and Fig. 11 are diagrams that show the combinations of thermal and auditory comfort and discomfort sensation as lines that represent the equal universal comfort and discomfort sensation, respectively. These lines are interpolated by means of the spline function. As shown in Fig. 10, when thermal comfort and auditory comfort indicates similar level on each scale, both of specific comfort sensation votes affect universal comfort, but when there is extreme difference between thermal and auditory comfort sensation level, the universal comfort is affected with the more uncomfortable one in specific comfort sensation, not with the comfortable one. Thus, when even there is an uncomfortable factor, the environment is finally estimated as uncomfortable, with little respect to comfortable feelings caused by another factors. Mori (1993) suggested that, when one attribute was processed in parallel through plural information, the human could perceive only simple information depending on the exclusive integration principle. If thermal and auditory comfort represents one psychological attribute, that is, the universal comfort in parallel, this findings support Mori’s Exclusivity Principle.

Fig. 12 and Fig. 13 are diagrams that show the combinations of thermal and auditory condition as lines that represent the equal universal comfort and discomfort sensation. The relationship between the universal comfort/discomfort sensation and two physical variables on the two dimensional space are not linear. These diagrams are equi-comfort and equi-discomfort charts respectively, constituted with the operative temperature and $L_{Aeq}$. Horie et al.(1985) and Sakurai et al.(1988) have proposed the additive model for the quantitative evaluation of the combined effects of temperature, noise and illuminance in the moderate stress environment. However, this model are inadequate while the above-mentioned exclusive integration principle stands, and has the validity only when the universal evaluation can be expressed as the addition of the degree of each environmental factor. Mori (1993) expressed insufficiently the combined effects of sound, luminance and tem-

![Fig. 12 Equi-comfort chart constituted with operative temperature and $L_{Aeq}$](image1)

![Fig. 13 Equi-discomfort chart constituted with operative temperature and $L_{Aeq}$](image2)
perature, because the experimental conditions of each environmental factor were constituted with only three levels and with narrow range. The charts as shown in Fig. 12 and Fig. 13 can quantitatively evaluate the combined effect of hot and noisy conditions, without restriction to such additive operation and moderate range of each environmental stress. Consequently, these charts make it possible to reasonably predict the human comfort and discomfort sensations from the given temperature and noise level within this experimental condition.

References

Horikoshi T. and Kobayashi Y. (1978) Configuration factors between a rectangular solid as a model of the human body and rectangular planes, for evaluation of the influence of thermal radiation on the human body II. Transactions of AIJ 267:91-101