Factors affecting comfort

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A paper previously published in Energy and Building, 14 (1990), under the title Quantification of the synthesized Evaluation of the Combined Environment, *by Y. Sakurai et al, Japan. Reprinted by permission of the Author.*

Author's Note: The research discussed in this paper was done some years ago. During the recent New Zealand Acoustical Society Conference in Auckland, there was considerable discussion on noise in the built environment, and as such it seems an appropriate time to review this work.

Introduction

Laboratory studies have been undertaken in an attempt to determine the effect that temperature, noise level, and illumination have on "comfortableness".

The studies were undertaken in Japan in the early 1980s using Japanese students, with each student undertaking repeated tests as each parameter was varied.

This paper reviews the results of three such experiments, and shows that "uncomfortableness" can be expressed by the addition of a weighted score for each parameter.

Noise is shown to be significantly less important in this rating than temperature.

Method

Voting Scale

It would be reasonable that an environmental engineer should make the effort to find how an improper environment could be avoided, rather than to find the desirable environment precisely, in order to give architects or planners much more freedom in their design. The term 'stress', which is used to express negative effects from physical and social aspects, suggests the existence of non-specific scales. Although evaluation means the judgment whether a certain condition is good or bad, this expression is too vague to utilise in the study of environmental evaluation.

From the words which have a close relationship with evaluation factor [8], "uncomfortable" is one of the most suitable words. An acceptable environmental condition is not restricted to the comfortable range and probably includes a slightly uncomfortable range in our daily life. Therefore "uncomfortable" is selected to mean the general environmental condition which is not felt to be comfortable.

When explanatory variables are discrete, and the relationship between a subjective vote and environmental factors as explanatory variables can be expressed as a linear combination, the second method of quantification [9-11] is very useful. This method is a kind of multiple discriminant analysis which utilises discrete variables.

As a suitable scale of synthesised evaluation, a one-sided scale of uncomfortableness is used, because the positive state of mind which feels comfortable cannot be kept indefinitely, but the negative state of mind which feels uncomfortable lasts steadily longer corresponding to such a condition. Since increasing the number of classes makes judgment more uncertain, only three classes have been used—"neutral", "slightly uncomfortable", and "uncomfortable".

Experiments

Experimental conditions in Table 1 were determined within the range which is presumed to be moderate. Four categories of thermal condition and noise level, and three categories of illuminance are used. Subjects were healthy Japanese male students 18-26 years old. All were volunteers and were paid reasonably. All were subjected to a hearing test and all were approved normal. CLO values were estimated to be 0.5 in summer, and 1.0 in winter.

An experimental chamber was installed in an anechoic room (5 x 6 x 3 m^3), which was lined with a thermal insulation layer (glass wool 200mm thick), and had wallpaper on the walls and the ceiling, and vinyl sheet flooring. Traffic noise recorded along a highway was fed into the chamber by two loudspeakers facing the wall to obtain a uniform level of noise

Category	Thermal Condition	Noise level (L_{eq})	Illuminance (lux)
1	21.8 [15.0][2]	40	170
2	26.2 [18.5]	50	700
3	30.7 [22.7]	60	1480
4	34.6 [26.1]	70	

Notes:
1. SET denotes Standard Effective Temperature, see later description
2. Values in [ ] are for winter.

Table 1: Selected conditions for each factor. Total number of experiments was 48 (4 x 4 x 3).

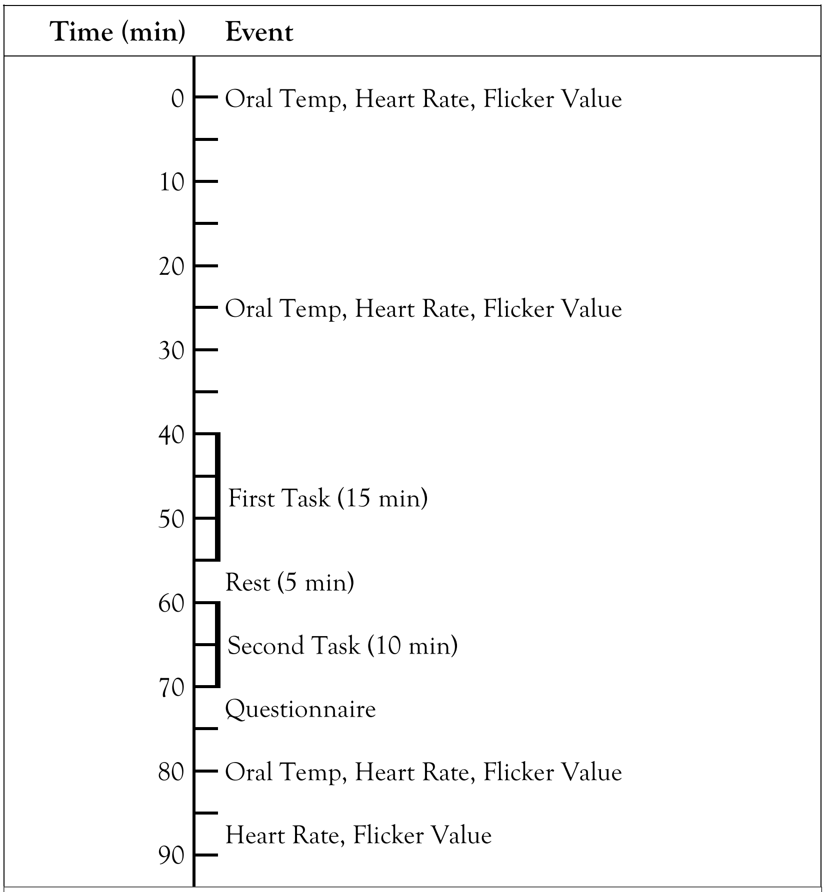

Figure 1: Experiment timetable

distribution. Subjects were exposed to the noise during their stay in the room. The desks were illuminated by two 20W white fluorescent lamps. The illuminance of the top of the desks was controlled by the voltage supply to the lamps. There was no general lighting. Thermal conditions were controlled with four electric heaters, two domestic coolers, and a fan to bring in fresh air.

Physiological measurements, performance and questionnaires assigned to the subjects during an experiment were scheduled as shown in Figure 1. Oral temperature, heart rate, and flicker value were measured. The Uchida-Kraepelin Test [12], which involves addition of two digit numbers, was adopted as a task. Subjects had no meals within two hours before the experiment and had no stimulants such as cigarettes and coffee within 30 minutes prior to the experiment. The test was conducted according to the old manner, i.e., 15 minutes for the first test, 5 minutes rest, then another test of 10 minutes. Skin temperatures were measured with 0.3mm diameter copper-constantan thermocouples on the back of the left hand, the left foot, and the medial thigh every minute throughout the experiment. Data was obtained from the printer output of a multi-channel temperature recorder in 1981, and by the tape cartridge of a personal computer via a data logger in 1982 and 1983.

What are CLO and SET?

Clothing insulation (CLO) Based on research on clothing insulation originally conducted for military purposes. 1 clo = 0.16°C .m^2/w (1 m^2 = 11 ft^2). The clo is a measure of thermal resistance and includes the insulation provided by any layer of trapped air between skin and clothing and insulation value of clothing itself. 1 clo unit will maintain a sedentary man at 1 met indefinitely comfortable in an environment of 21°C (69.8°F), 50% RH, and .01 m/s (20 ft/min) air movement. Assuming no wind penetration and no body movements to pump air around, clothing insulation = 0.15 x weight of clothes in lbs. (i.e., 0.15 clo per lb of clothes). So 10 lbs. clothes = 1.5 clo.

Standard Effective Temperature (SET) - SET is the temperature of an isothermal environment which has air and mean radiant temperature equal to each other, RH of 50%, still air, and in which a person with a standard level of clothing insulation would have the same heat loss at the same mean skin temperature and the same skin wettedness as the person has in the actual environment with the clothing insulation under consideration. The activity level is assumed to be the same in both environments.

The main purpose of the task was to avoid a bias of votes caused by undue attention to the environment. Subjects were instructed that the performance of the task was the main purpose and to do the addition as fast as possible.

Although four subjects participated at a time in principle, in some cases three subjects did. The number of combinations of the three environmental factors was 48 (= 4 x 4 x 3). The total number of samples was up to 192 in each set of experiments. Since it is desirable to use as many samples as possible to get reliable results, more than 500 samples were obtained in summer and winter, by summing the three years' samples (1981 – 1983).

Results

The second method of quantification [9-11] was applied to obtain quantitative scores which are useful for the environmental design of a building. In this method, an explanatory variable and an outside criterion are used for an environmental factor and an uncomfortableness vote, respectively. Correlation ration n^{2}, or its square root, is a measure of distinction of the classes of the outside criterion. The category score means the weight of each factor on the outside criterion.

The thermal condition was changed by changing air temperature, and the quantification was initially done using only dry-bulb temperature. However, since the other thermal conditions—humidity and globe temperature—were measured simultaneously, it was expressed in Standard Effective Temperature (SET). Since the extension of thermal condition to SET has been verified [4], the results are shown with this category in terms of SET. The results for both summer and winter are shown in Table 2. The square root of the correlation ratio (η) for summer was 0.77 – large enough to obtain a reliable prediction. Experiments were conducted over three different years, and the score profile in each year is not so different from each other. The samples of each year were bound and the quantification was done by samples in three years.

Thermal condition is clearly the dominant contributor of the three factors for the judgment of uncomfortableness – not surprising considering a typical Japanese summer. Judging from the scores of each category, the least uncomfortable thermal condition exists around 21.8 °C (SET). Uncomfortableness caused by noise correlates with its level, but does not change linearly. In comparison with 70 L_{eq}, the perceived difference in uncomfortableness at levels of 40, 50, or 60 L_{eq} is very small.

The partial correlation coefficient

Factor	Summer	$N = 538$	$\eta = 0.77$	Winter	$N = 549$	$\eta = 0.62$
	Category	Score	PCC[1]	Category	Score	PCC[1]
Thermal Condition (SET[2])	21.8	0.762	0.762	15.0	–1.480	0.569
	26.2	0.706		18.5	0.051	
	30.7	0.180		22.7	0.688	
	34.6	–1.637		26.1	0.697	
Noise (L_{eq})	40	0.168	0.257	40	0.436	0.325
	50	0.151		50	0.337	
	60	0.052		60	–0.097	
	70	–0.374		70	–0.676	
Illuminance (lux)	170	–0.057	0.053	170	–0.271	0.158
	700	0.006		700	0.207	
	1480	0.052		1480	0.080	

Note: 1. PCC = Partial Correlation Coefficient
2. SET = Standard Effective Temperature, see description elsewhere.

Table 2: Category scores

(PCC) of illuminance, which shows the contribution of this factor to the uncomfortableness was small, perhaps because of its rather narrow range. Generally speaking, illuminance does not contribute to uncomfortableness as much as the two other factors, if it is within the range applied here.

The results in winter are also shown in Table 2. The square root of the correlation ratio was smaller than that in summer. This is probably caused by the smaller contribution of thermal condition, which shows a smaller PCC. The contribution of noise was clearly smaller than that of thermal condition, although it was slightly larger than that in summer. The contribution of illuminance is as small as in summer. From these scores, the least uncomfortable thermal condition exists around 26.1 °C (SET), the contribution of noise was a little greater than in summer, and a category score for illuminance was reasonable, though we cannot rely much on the illuminance scores because of the small category scores and PCC.

Discussion

The scores for the categories of three factors were obtained by the second method of quantification as shown in Table 2. To determine a correct class for a total score, it is necessary to determine a combined probability for all three categories.

In figure 2, it is assumed that the probability distribution of subjective votes in each class is Gaussian, and the dividing points z_1 and z_2 were found, so that the area within each distribution from $-\infty$ to z_1, from z_1 to z_2, and from z_2 to $+\infty$ was equal, following the min-max method when the probability of the response to each class is unknown [11]. These dividing points are listed in Table 3. The success rate of prediction was 0.70 in summer and 0.61 in winter, which were calculated with the real distribution of the samples.

The category scores in Table 2 are given for discrete values of each category. The score for any other arbitrary value of a factor can be calculated by linear interpolation of the values given in the Table. After a total score is obtained by the sum of each factor's score, the zone divided by z_1 and z_2 which contains the total score, predicts a class of uncomfortableness to which the combined condition belongs.

The following two examples, using Tables 2 and 3, illustrate this method.

1. When the noise level is 55 L_{eq}, the thermal condition is 28.4 °C (SET), and illumination is 700 Lux in Summer, the noise score equals 0.102 and the thermal score equals 0.442 by linear interpolation, and the illumination score equals 0.006, and the total score is 0.551. Compared with the dividing points from Table 3, this environment falls just above z_2, and is therefore evaluated as neutral.

2. How should the thermal condition be designed in summer when a 'neutral' condition is aimed at, and a noise level of 50 L_{eq} and illuminance of 700 Lux are inevitable? In order to be neutral, the total score must be higher than

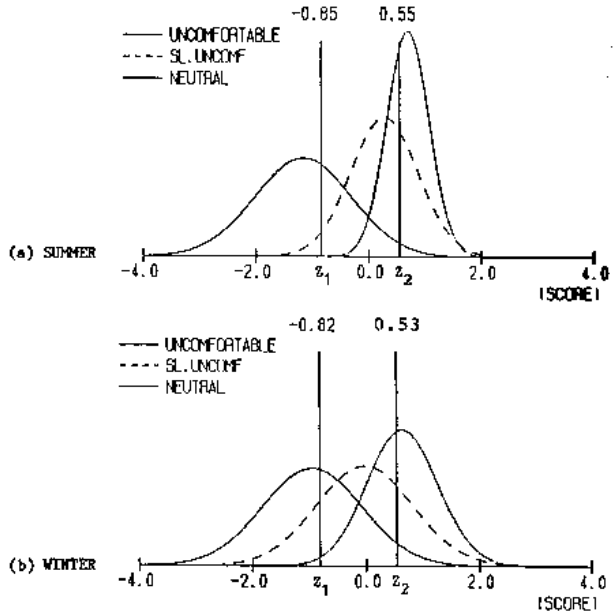

Figure 2: Probability distribution of total scores.

Condition	Dividing Point	Summer	Winter
Uncomfortable			
	Z_1	–0.85	-0.82
Slightly uncomfortable			
	Z_2	0.55	0.53
Neutral			

Table 3: Dividing points between adjacent classes, obtained from the data of three years. Refer Fig 2.

0.55. The two inevitable factors give a noise score of 0.151 for noise, and 0.006 for illuminance respectively. From the inequality 0.151 + 0.006 + thermal score > 0.55, the thermal score must be higher than 0.393. Interpolating between 26.2 °C (SET) and 30.7 °C (SET), the thermal condition must be kept lower than 28.9 °C (SET).

Conclusions

A synthesised evaluation of uncomfortableness caused by moderate ranges of stress composed of thermal condition, noise and illuminance can be simulated by the linear combination of the score for each category of three environmental factors, and these category scores are obtained by the second method of quantification. In a moderate range of an environmental condition, each effect of these heterogeneous factors can be evaluated on a common scale and therefore can be compared with each other. This result makes it possible to predict an evaluation of a combined environment and to improve the combined environment from comprehensive viewpoints.

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Upcoming Events

2003

Apr 7-9, Melbourne
WESPAC 8
Acoustics on the Move
Details: Mick Gould
convention@optushome.com.au
www.wespac8.com

Apr 28 - May 02, Nashville.
145th Meeting of the Acoustical Society of America
Details:
fax: +1 516 576 2377
web: http://asa.aip.org

May 19-21, Naples
Euronoise 2003.
Details:
fax 39 81 239 0364
www.euronoise2003.it

June 16-18, Cadiz
Acoustics 2003—Third Int Conf on Modelling and Experimental Measurements in Acoustics
www.wessex.ac.uk/conferences/2003/acoustics03

June 23-25, Cleveland
2003 Nat Conf Noise Control Engineering
Details:
fax: 1 515294 3528
email: ibo@ince.org

June 29—July 3, Rotterdam
8th ICBEN Congress—Noise as a public health problem
Details: www.icben.org

July 7-11, Stockholm
Tenth International Congress on Sound and Vibration
iscv10@congrex.se
www.congrex.com/icsv10

July 14-16, Southampton
8th International Conference on Recent Advances in Structural Dynamics
Details: Anne-Marie McDonnell
amtm@isvr.soton.ac.uk
www.isvr.soton.ac.uk/sd2003/

July 27-30, College Park,USA. 1st Conference on Acoustic Communication by Animals
Details:
fax: +1 516 576 2377
web: http://asa.aip.org

Aug 6-9, Stockholm
Stockholm Music Acoustics Conference 2003
Details:
www.speech.kth.se/music/smac03

Aug 25-28, Korea
Inter-Noise 2003
Details:
internoise2003@covanpco.co.kr
www.internoise2003.com

Sept 7—10, Paris
World Congress on Ultrasonics
www.sfa.asso.fr/wcu2003

Sept 23-25, Senli
2nd Int Symposium on Fan Noise
Details:
fax: 33 4 72 44 49 99
www.fan-noise2003.org

2004

Apr 4—9, Kyoto
18th International Congress on Acoustics (ICA 2004)
www.ica2004.or.jp

Aug 3-7, Evanston
8th Int Conf of Music Perception and Cognition
Details:
www.icmpc.org/conferences.html

Sept 24-27, Prague
Inter-Noise 2004
Details:
fax: 1 765 494 0787

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