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THE INFLUENCE ON TEMPERATURE OF NOISE, AIR VELOCITY AND WINDOW AREA DURING CHAMBER TESTS

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ABSTRACT

When establishing the optimal level of an indoor climate parameter in a limited economy, there is often a cost expressed as a reduced comfort level for one or more of the other parameters. Very little knowledge currently exists regarding optimal levels when two or more parameters are linked. There is an obvious need for empirical determination of the trade-off between some of these parameters. Thirty (30) heat-adapted subjects participated in ten 3.5 hour exposures in climate chambers. Each subject had the option to change the air temperature in the chamber by adjusting a vote knob when prompted every five minutes. The subjects were exposed to temperature linked with each of the parameters noise, air velocity and window area in a randomized design. In a reference exposure, temperature was not linked with the other parameters. They were given instructions to optimize the climate in their respective chambers by adjusting the temperature while acknowledging the cost in one of the other parameters. During the last 15 minutes of each exposure the perceptions of subjects, skin temperatures and simple performance measures were registered. A warmer temperature was increasingly preferred when each of the parameters noise, air velocity and window area became more costly.

I. Introduction

A large majority of the indoor climate research that has been done is applicable for countries whose outdoor weather conditions and resources are very different from most tropical regions of the world. Lowering the temperatures indoors in a hot region may be expensive. Optimizing the trade-off between linked parameters is a next-best solution when resources are scarce. As the following examples indicate, temperature is often linked with air velocity, noise and daylight.

1. A fan is a well known means of reducing heat stress in a warm environment. The reduced heat stress makes it pleasant to have some air movement (1). The sensation of draft created by air velocities in the range of 0.05 m/s to 0.5 m/s has been studied by Fanger et.al (2). The study gave maximum air velocities for comfort at comfortable temperatures. In warm environments, fans are in widespread use for the reduction of heat stress therefore knowledge on the effect of elevated temperatures on preferred air velocities needs to be created.

2. Some air conditioners are too noisy when turned on. The noise from an air conditioning unit will reduce people's willingness to reduce the temperature in a warm room. Makers of air conditioners have at present no scientific basis for deciding the relation their units should have between cooling effect and noise generation for users to consider them beneficial.

3. In a warm climate, windows may be reduced in area or completely removed to avoid the heat contribution from solar radiation. Sky luminance and artificial lighting are not the main factors which govern the choice of window size but rather visual contact with the outside which relieves the sense of enclosure (3). It may therefore be more acceptable to allow the temperature to increase and still have visual contact with the surroundings.

These examples indicate everyday optimization tasks in warm environments involving the trade-off between two parameters. Decisions on the balancing of the two indoor climate parameters are often made by building designers. Because there is limited scientific background for this balancing of parameters, the risk is that the balance point is not in agreement with the wishes of the future building users. There is an obvious need for empirical verification of the trade-off between the parameters.

II. Method

Thirty (30) paid human subjects participated in ten exposures each lasting approximately 3.5 hours in each of three single-person climate chambers. Before the exposures they were given written and verbal instructions on procedures and behavior during the experiments. They were allowed to read or to do other activities which simulated working in an office. Each subject was exposed to temperature linked with noise pressure, temperature linked with air velocity, temperature linked with window area, and a base exposure were temperature was not linked. The exposure were sequenced in a randomized design. During exposures the subjects adjusted the air temperature in the chamber by adjusting a vote knob. A 7-point vote scale was used to make these adjustments (much cooler, cooler, slightly cooler, no change, slightly warmer, warmer, much warmer). They were given instructions to optimize their chamber environments but were made aware that selecting a cooler temperature would either reduce the window opening, increase the noise level, or increase the draft depending on the chamber they were in. In the base exposure, they could freely select the temperature they felt most comfortable with without any window, draft, or noise expense. They were prompted to vote every 5 minutes during the first hour and every ten minutes thereafter. Data for the subjects are shown in Table 1.

The design of the chambers is shown in Figure 1. A flow of 120 l/s cooled and dehumidified air was equally distributed to each of the three ducts leading to each chamber. An additional fan, which re-circulated the chamber air by 110 l/s, and a 1800 W air heater, which was controlled by a temperature controller, were used to ensure a fast temperature response whenever the temperature in the chamber had to be varied in response to a subject's vote. Each exposure was done with a fixed linear relation to one of the parameters noise, draft and window opening. In Chamber 1, temperature was tied to window area. It was adjusted using a sliding door on the outer side of the window. Equal graduations were made to adjust the position of the sliding door from the fully closed position to the fully open position. The window was adjacent to a pleasant backdrop of trees and was not exposed to direct sunlight. In Chamber 2, temperature was tied to air velocity. It was generated by a traditional stand fan diagonally behind the subject and was adjusted by varying the voltage input to the fan. Average air velocity for a seated subject when the stand fan was off was less than 0.1 m/s. In Chamber 3, temperature was tied to noise. It was generated using tape recorded air-con noise and the level adjustments were done by adjusting the playback equipment volume control knob. The chamber system design is described in detail in (4).

Every 60 minutes, the subjects were asked to complete a questionnaire and experimenters measured and observed their reactions. Temperatures and humidities were measured by an automated data logging system every 5 minutes. The links between temperature and either noise pressure, draft or window area were not know to the subjects. In the statistical analyses only the data logged during the last 20 minutes was used. If the subject consistently voted "no change" during the last 20 minutes of the exposure (therefore indicating an optimal condition), then the data point was considered. Otherwise, the offset of the votes was used to change the operative temperature and the linked parameter into an estimate of what the subject may have wanted - which was the average operative temperature during the last 20 minutes of the hour. When the average of the votes during the last 20 minutes deviated by more than 1 vote point away from "no change" (therefore indicating a non-optimal condition), the data point was disregarded.

III. Results

Figures 2-4 show the results. The points at no cost are the same for all figures. The preferred operative temperature when temperature was not linked was 25.3 °C and the standard deviation was 1.8 °C. The dotted lines indicate the approximate path of the optimum trade-off between the linked parameters.

Operative Temperature vs. Noise Level

Figure 2 shows preferred temperatures tended to become higher when the noise tie became more expensive (that is, much more increase in noise level for a decrease in operative temperature). As the tie became more expensive the subjects increasingly chose a warmer temperature and the optimum trade-off increased from 0.09 °C/dB to 0.14 °C/dB to 0.30 °C/dB.

Operative Temperature vs. Draft

Figure 3 shows a rather linear trade-off trend. As the tie became more expensive (that is, much more increase in draft for a decrease in operative temperature), the optimum trade-off only slightly changed from 5.6 °C/m/s to 6.4 °Cm/s to 7.1 °C/m/s. Preferred temperatures tended to become higher as the tie became more expensive. (Approximately 0.4 m/s was the lowest average velocity that could be achieved when the stand fan started rotating.)

Operative Temperature vs. Window Area

Although this is expectedly the weakest relationship, Figure 4 shows that when the tie became more expensive (that is, much less increase in window opening for an increase in operative temperature) optimum trade-off changed from -1.37 °C/m^2 to -1.05 °C/m^2 to -0.40 °C/m^2.

Choosing a warmer temperature became increasingly less preferred and increasingly less important as the tie became more expensive.

The standard error of the mean as a percentage of the sample mean varied from 1.00% to 1.33% for all the different ties.

IV. Discussion

The group average neutral temperature in this study of 25.3 °C was in close agreement with the neutral temperature reported by Fanger (5) (25.6 °C). The standard deviation of the neutral temperature of 1.8°C was larger than that found by Wyon and Sandberg (6) in a field experiment with office workers wearing their normal clothes and doing regular office work (S.D. 1.2 °C). The difference could be attributed to the subjects being confined to the chambers in this study unlike in the field study where people were free to move around and interact with one another. Grivel and Candas (7) have shown that neutral temperatures may have a standard deviation of 2.6 °C when subjects used standard clothing and no task in a climate chamber.

Results are in agreement with Clausen et.al. (8) showing a relation between temperature and traffic noise of 0.26 °C/dB and a similar tendency to perceive noise more costly at the higher noise levels. Thirteen (13) window-mounted air conditioners were surveyed and the average noise level was 62.5 dB ± 5.2 dB. In a warm climate, if an air conditioner is used to provide cooling up to 28.5 °C noise should be less than 78 dB, up to 27.5 °C less than 75 dB, up to 26.3 °C less than 66.8 dB and up to 25.3 °C less than 56 dB or no overall subjective benefit will be experienced.

The typical increase in temperature by a single glass window in a tropical climate not exposed to direct sunlight when around 7% of the floor area are windows is 0.25 °C/m^2. If a window area adjacent to a pleasant view were reduced to reduce the heat gain from a warm ambient, the reduction should be less than 1 m^2/°C to maintain the subjective comfort level.

If a fan is used to provide additional cooling when temperatures rise above 25.3 °C, the average draft increase should be 0.18 m/s per °C from 25.3 to 28.0 °C, 0.16 m/s-°K from 28.0 to 28.5 °C, and 0.14 m/s-°K from 28.5 to 29.0 °C to maintain the subjective comfort level. The findings indicate that there is a trade-off between temperature and the non-thermal factors of air-con noise, increased draft and decreased window area. This clearly shows the weakness of conventional means of predicting comfort levels from single-parameter studies.

In hot climates, knowledge of the optimum levels of indoor climate parameters when they are linked together is important if best productivity levels are to be achieved within the little resources available. The results of this study may be used as a basis for updating regulating codes to compel building designers to specify equipment that are in agreement with the indoor climate parameter preferences of the future users of the building.

V. Conclusions

Trade-off studies have been shown to give relevant results. This type of unified scaling research may give important information on the proportions of users' perceptions of the indoor climate. Continued research is recommended.

Specifying the optimum trade-off between linked parameters is a next-best solution when resources are scarce.

Continuing research activities in these and related areas can do much to improve the quality of the indoor environmental in limited economies as they become the basis for updating regulating codes.

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Table 1
Data for the 16 males and 14 females in the experiments

		AGE (YEARS)	HEIGHT (M)	WEIGHT (KG)	CLOTHING (CLO)	AIR-CON TIME (H/DAY)
All Subjects	Mean	25.1	1.66	63.2	0.528	3.15
	S.D.	6.32	0.10	14.1	0.056	3.19
Males only	Mean	22.9	1.72	66.0	0.548	3.38
	S.D.	4.31	0.08	15.4	0.062	3.58
Females only	Mean	27.6	1.59	60.0	0.505	2.89
	S.D.	7.43	0.06	12.1	0.039	2.80

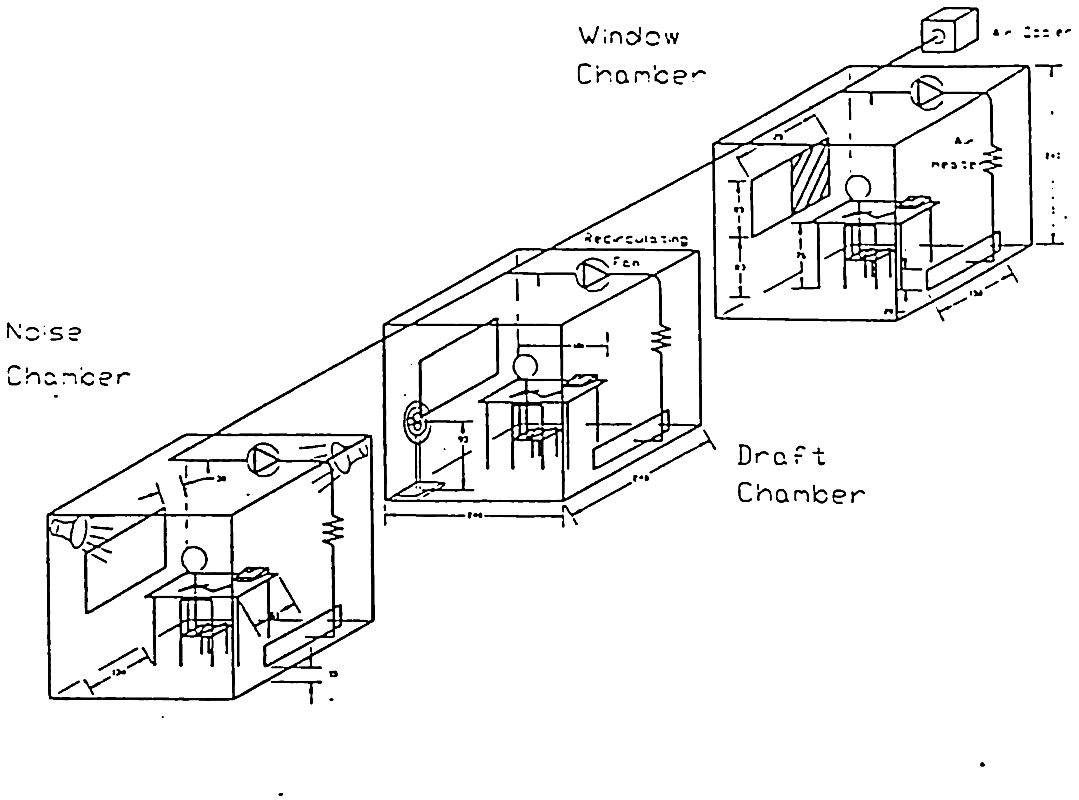

Figure 1. The chamber system used for the experiments. Dimensions are in cm.

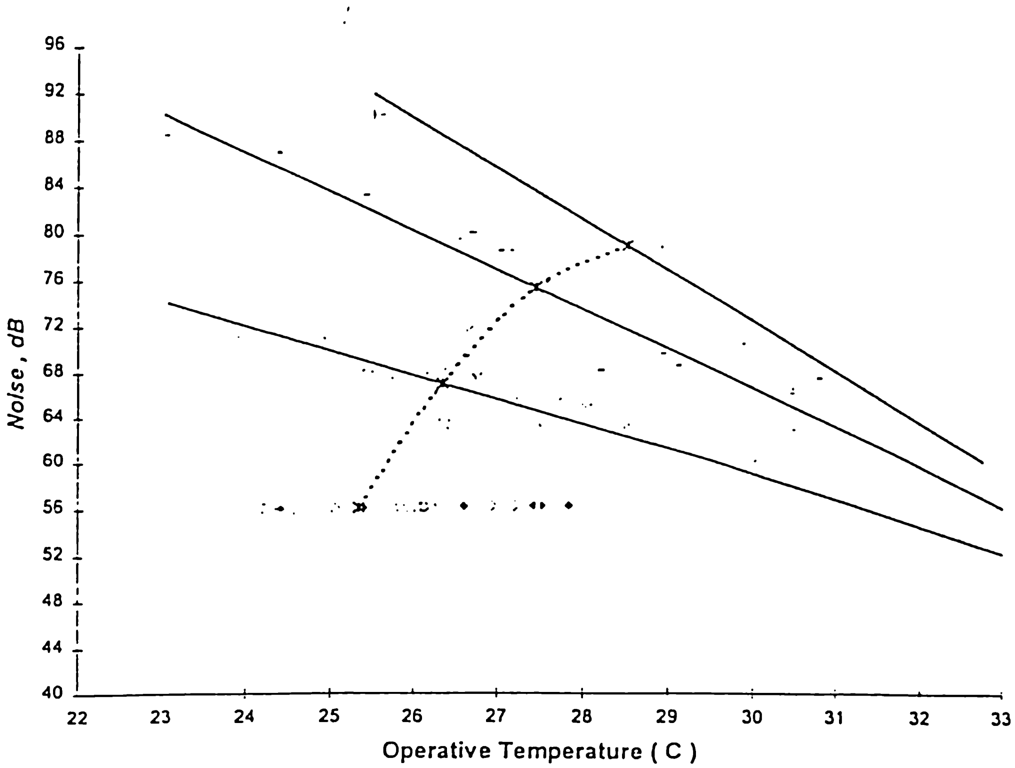

Figure 2. Trade-off between temperature and noise.

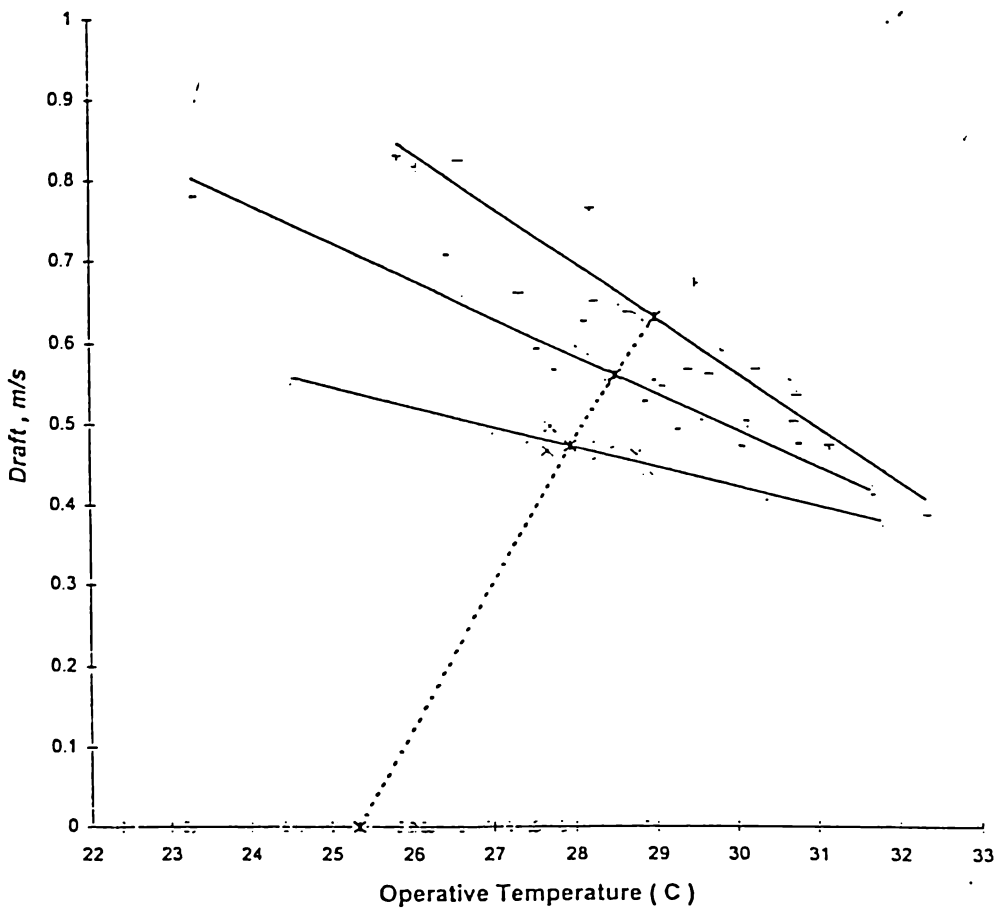

Figure 3. Trade-off between temperature and draft.

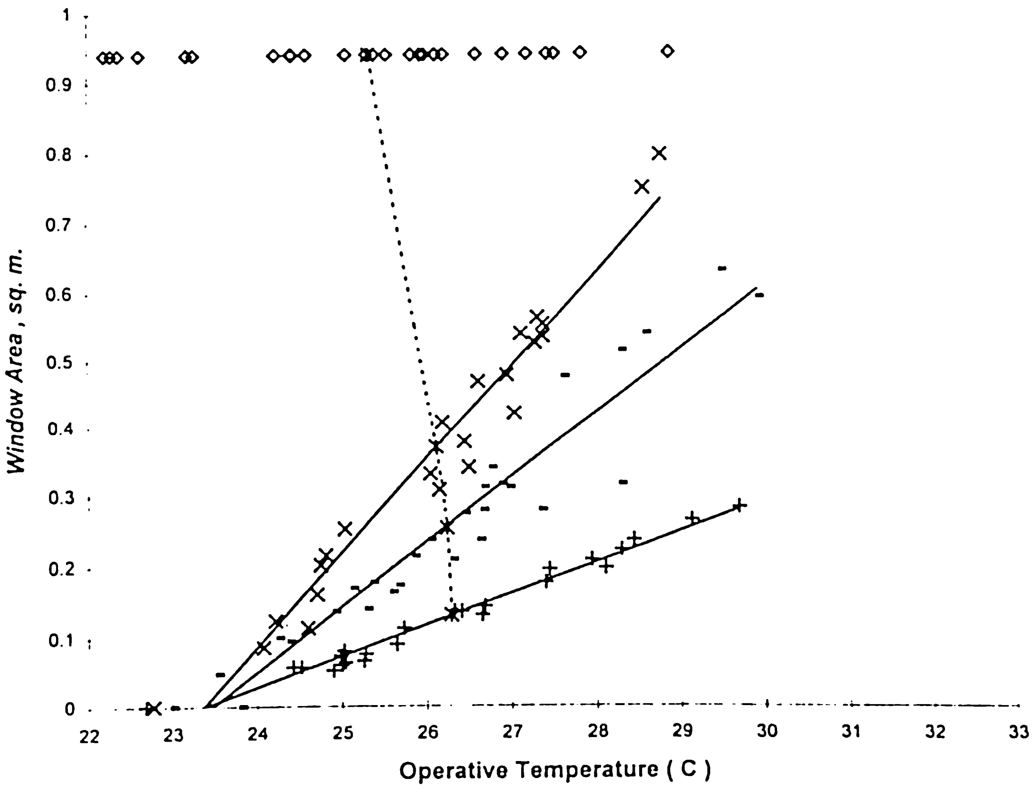

Figure 4. Trade-off between temperature and window area.