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RELATIVE IMPORTANCE OF TEMPERATURE, DRAFT, NOISE AND WINDOW AREA IN OFFICES

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ABSTRACT

Achieving optimized partial improvements of the indoor climate may often be better than to know all optimal levels. The purpose of this study was to investigate the relative importance of temperature, noise, draft and window area. 30 heat-acclimatized subjects participated in 10 exposures in single person climate chambers. Each exposure lasted three hours. During an exposure, the subject was free to optimize the operative temperature at a link to either draft, noise or window area. For each pair of parameters, three linear links were tested. A reference exposure was furthermore included without any link. Results show that a decrease in operative temperature of 1 °C gives the same decrease in annoyance as approximately 0.1 m/s decreased air velocity, 7 dB(A) decreased noise level or 0.5 m^2 increased window area. The used trade-off method may have numerous other research applications.

KEYWORDS

Trade-off, temperature, heat stress, hot climate, draft, noise, window area, chamber tests, heat acclimatized subjects.

INTRODUCTION

Indoor climate studies have resulted in building codes that often give a positive input to the lives of people. Knowledge about particular problems in hot and humid tropical climates is still limited. Developing countries in hot and humid regions face particular restraints in the adoption of many technical solutions to indoor climate problems. Specifically, the installation and running costs of many solutions known from developed countries may be prohibitive. There is a need for fundamental and applied research focused on the indoor climate needs of developing countries in hot and humid tropical regions.

Predicting comfort levels has been conventionally done by single-parameter studies. The focus of this report is to determine the trade-off when temperature is linked with the parameters of window area, air velocity and noise in a warm climate.

Windows may be reduced in area or completely blocked to avoid the heat contribution from solar radiation. Ne'eman and Hopkinson (1970) have shown that sky luminance and artificial lighting levels 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. It may therefore be more acceptable to allow the temperature to increase and still have visual contact with the surroundings.

A fan is a well-known means of reducing heat stress. The increased air velocity may however result in draft annoyance. The sensation of draft created by air velocities has been studied by Fanger et al. (1988). The study gave maximum air velocities for comfort at neutral temperatures – when there was no sensation of feeling slightly warm or slightly cool. For the typical application where fans are used to reduce heat stress, the study may have limited relevance.

Some air-conditioners are rather noisy when turned on. The noise from an air conditioning unit will reduce people's willingness to reduce the temperature in a warm room. Clausen et al. (1993) have tried to establish equally comfortable environments by varying either noise, temperature or air quality. Their experiments were performed with only one parameter at a reduced level at a time. A more realistic situation where the parameters are linked was not attempted. Makers of air conditioners have at present limited scientific basis for deciding the relation their units should have between cooling effect and noise generation for users to consider them beneficial.

Often, decisions on the balancing of two indoor climate parameters are made by building designers. Because there have been very few scientific studies to date for this balancing of parameters, the risk is that the chosen balance points will not be in agreement with the wishes of the building users. There is an obvious need for empirical verification of the optimal or desired trade-off between parameters of the indoor climate.

METHOD

Trade-off effects were studied using heat acclimatized human subjects in climate chambers with a fast system for temperature control. Three single-person climate chambers were made for this study. 30 paid human subjects participated in ten exposures each lasting approximately three hours in the chambers. They had lived all their lives in the hot and humid tropical climate of the Philippines. Data for the subjects including the average time they reported to spend in air-conditioned spaces are shown in Table 1. Each subject was in a randomized plan exposed to temperature at three different linear links to either recorded noise from an air conditioner, air velocity from a stand fan, or window area. A reference exposure where temperature was not linked with the trade-off parameters was furthermore included. The subjects were given instructions to optimize their chamber environments by giving temperature votes on the Bedford scale. They were made aware that a cooler temperature closer to thermal comfort would reduce the window opening, increase the noise level, or increase the draft in a consistent way through each exposure. They were not getting any further information but initial experimenting was encouraged. In the base exposure, they could freely vote for the temperature they felt most comfortable with without any window, draft, or noise cost.

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	Mean	25.1	1.66	63.2	0.53	3.1
Subjects	St. d.	6.32	0.10	14.1	0.06	3.2
Males	Mean	22.9	1.72	66.0	0.55	3.4
Only	St. d.	4.31	0.08	15.4	0.06	3.6
Females	Mean	27.6	1.59	60.0	0.51	2.9
Only	St. d.	7.43	0.06	12.1	0.04	2.8

Temperature and humidity were measured by an automated data logging system every 5 minutes in several locations according to Figure 1. In the statistical analyses, only the average value of the data logged during the last 20 minutes of each hour was used. When the absolute value of the average vote was outside the range "Slightly warmer" to "Slightly cooler" the data were disregarded.

The climate chambers

Three single-person climate chambers were used (Garcia et al. 1997). Each chamber measured 2.27 x 2.27 x 2.27 m^3 inside. The walls, floor and ceiling of the chambers were made of two layers of plywood with 50 mm Styrofoam insulation between. The overall heat transfer coefficient of the chamber was 37.2 W/K including window and door. The chambers were all placed in a naturally ventilated room of approximately 95 m^2 with an air change rate of 2 h^{-1}. All chambers had a 0.94 m^2 double-glazed window. The view from these windows was a pleasant backdrop of trees seen through the metal grills and windows of the surrounding room. Supplementary lighting for the chambers came from two 40-watt incandescent bulbs.

The air handling system

Figure 1 shows schematically the three chambers and duct system. Outside air went through the cooling coil of a modified window mounted air-conditioning unit before it was equally distributed to the chambers by the duct system shown. A flow of about 40 l/s cooled and dehumidified outside air was supplied to each of the chambers providing all the cooling. This supply air mixed with the return air that was extracted from the top of the chamber. An additional fan re-circulated the chamber air. Displacement ventilation was employed. Excess air could escape the chamber via an opening above the door. The air velocity reaching a seated subject was less than 0.10 m/s. An electric air heater connected to a PID temperature controller with feed back from the sensor for chamber air temperature maintained temperature. The temperature in the chamber was varied by the experimenters by adjusting the controller's set point in response to the subject's vote.

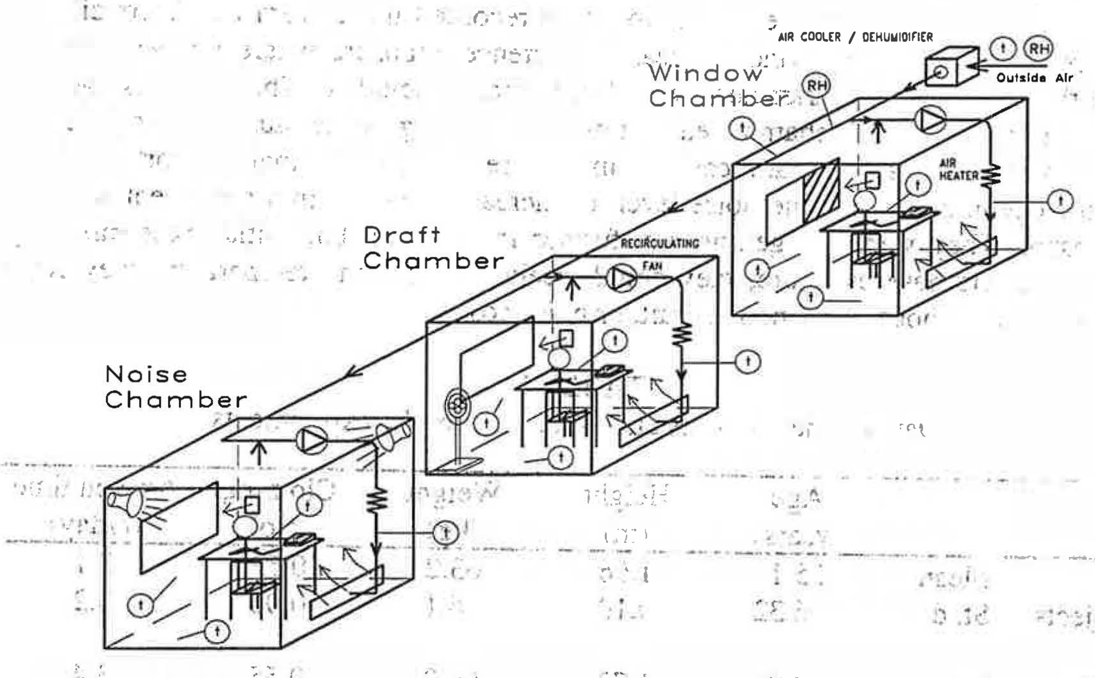

Figure 1. System schematic diagram showing the three climate chambers, ductwork, and location of the temperature and humidity sensors

RESULTS

Figure 2 shows respectively the mean window area, air velocity and noise versus mean operative temperature for each subject during the last 20 minutes of each exposures in the chambers. Lines

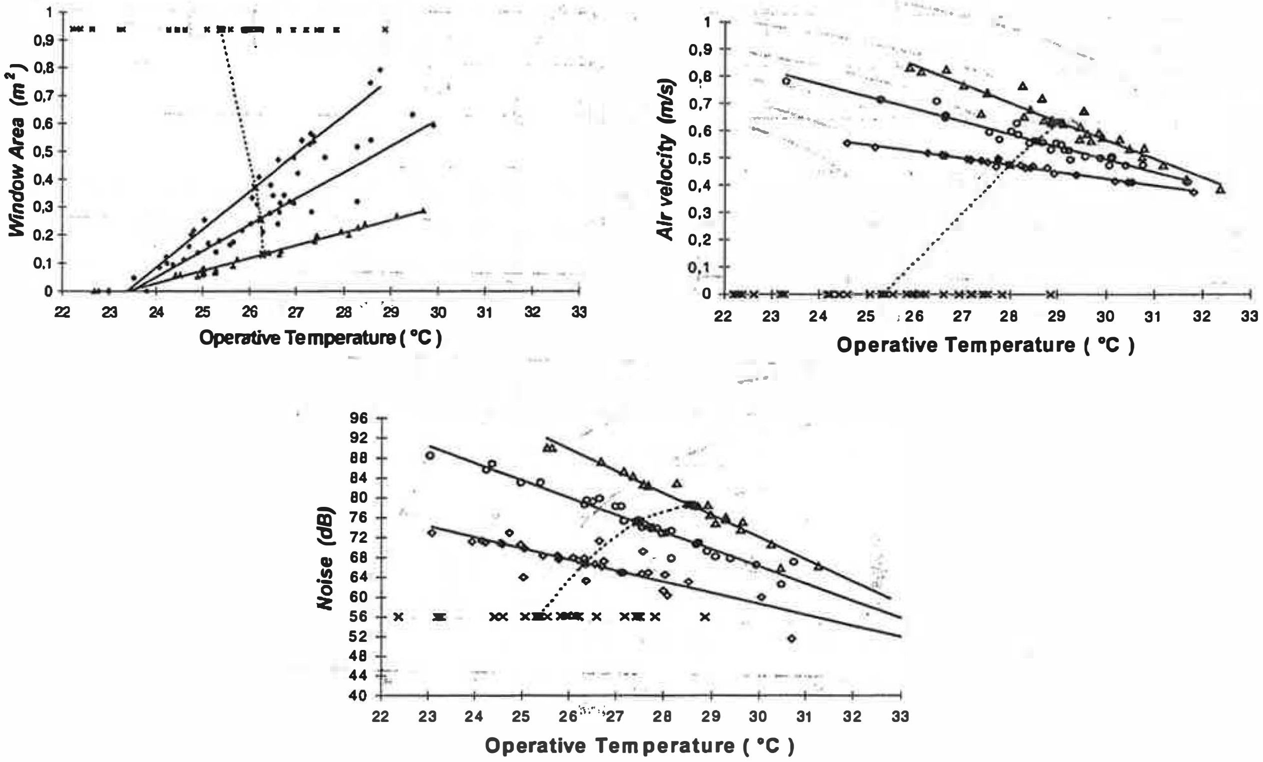

Figure 2. Mean window area, air velocity and noise shown in relation to operative temperature during the last 20 minutes of exposures for each subject. The same reference exposures are shown in all three charts. Full lines indicate the linear ties and the dotted lines gives preferred mean settings at the linear ties.

for the cost ties are shown as solid lines. The dotted lines are the curve for preferred mean changes during the used trade-off ties.

Using a computerized procedure for general linear models, several different types of formulas were tested to fit the observations. The best fitting models were found to be:

$T_o = 23.90 + 3.30\ 1/A\ dA/dT_o + 0.47\ t$ for window area

$T_o = 23.74 + 2.89\sqrt{V} - 16.49\sqrt{V}.dV/dT_o + 0.53\ t$ for air velocity

$T_o = 24.07 - 0.0000907\ N^2\ dN/dT_o + 0.36\ t$ for noise

T_o	:	Operative temperature in the chamber (°C)
A	:	Window area (m^2)
V	:	Average air velocity (draft) reaching the person (m/s)
N	:	Noise pressure reaching a person in the chamber (dB_A)
t	:	Time (hours)

Removing the differentials by analytically solving the equations is possible for window area and noise leading to the following expressions for t = 3 h

$0.5\ T_o^2 - 25.31\ T_o = 3.30 \ln A + K$ for window area

$0.5\ T_o^2 - 25.15\ T_o = (0.333)\ 0.0000907\ N^3 + K$ for noise

A and T_o respectively N and T_o gives constant annoyance for constant K.

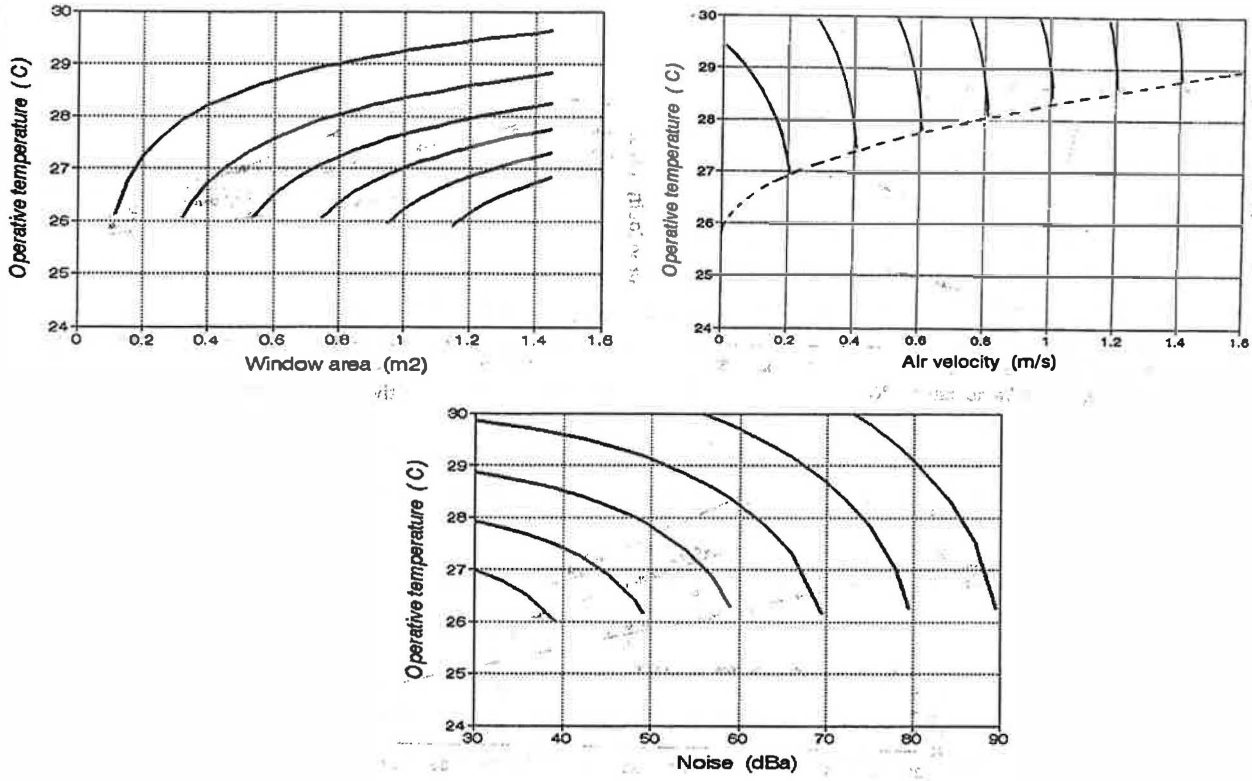

Figure 3. Lines for constant annoyance at simultaneous exposure to temperatures higher than comfortable and window area, air velocity and noise.

For air velocity, the differential equation may not be solved analytically. Geometrically constructed solutions for the air velocity equation are shown in Figure 3 with graphical presentations of the analytical solutions for the equations for window area and noise. The figure may be used to determine whether a change in the depicted pairs of parameters will be perceived as an overall improvement or the opposite.

DISCUSSION

These experiments reveal a significant trade-off between temperature and decreased window area, increased draft and increased air-conditioner noise. This clearly shows the power of the developed and applied experimental method compared to conventional means of predicting comfort levels from single-parameter studies.

Figure 3 may be used as a guide to improvements in user's perception of overall indoor quality when for example using air velocity or blockage of windows as a means to reduce heat stress. Makers of air-conditioning equipment may use the figure to evaluate the effect of noise reduction measures for their equipment.

During the window and air velocity exposures the preferred operative temperature was reduced by an average of 0.50 °C per hour of exposure while the reduction was only 0.36 °C per hour during the noise exposures. The temperature reduction is probably caused by subjects relaxing more and more therefore getting a lower metabolic rate. The higher noise levels probably cause some arousal, which counteracts this effect.

The average neutral temperature in this study of 25.3 °C was in close agreement with the neutral temperature (25.6 °C) that was reported by Fanger (1972) for the same activity and clothing. The standard deviation of the neutral temperature was 1.8 °C in this study. Somewhat larger than that found by Wyon and Sandberg (1996) in a field experiment with office workers wearing their normal clothes and doing regular office work (St. d. 1.2 °C). Grivel and Candas (1991) showed that neutral temperatures may have a standard deviation of 2.6 °C when subjects used standard clothing and no task in a climate chamber. The subjects in this study used their own clothing but as shown in Table 1 the individual freedom to adjust one's clothing according to personal thermal requirements is less in a warm environment. A standard deviation on preferred temperatures slightly higher than for Swedish office workers could be expected.

Results for the noise operative temperature trade-off giving values for the near comfortable temperatures in the range 0.1 – 0.4 °C/dB_A are in fair agreement with Clausen et al. (1993). Their results show a relation between temperature and traffic noise of approximately 0.26 °C/dB_A and a similar tendency to perceive noise more costly at the higher noise levels.

13 window-mounted air conditioners were surveyed in offices in Quezon City, Philippines and the average noise level was 62.5 dB_A with a standard deviation of 5.2 dB_A. Several of these were more noisy than recommendable for the heat stress relief they provided.

CONCLUSIONS

These experiments reveal a significant trade-off between temperature and window area, draft and air-conditioner noise. This shows the power of the developed and applied experimental method. It also shows limitations in conventional means of predicting comfort levels from single-parameter studies.

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. 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 assure the best possible quality of the indoor environment in countries with limited economies as this type of research may become the basis for updating regulating codes.

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