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What causes discomfort?

technical file

Air temperature, poor air quality and excess noise all determine the level of occupant satisfaction in buildings, but how do they interact? Researchers at the Technical University of Denmark present the findings of their comparative study.

Most research on indoor air quality and on thermal and acoustic environments has focused on the impact on human comfort of just one particular parameter. However, in practice people are very often exposed to combinations of two or more environmental parameters simultaneously.

Attempts to reduce one cause of discomfort may increase other types of discomfort. For example, opening an office window to a noisy outdoor environment will sacrifice acoustic comfort for either increased thermal comfort or better air quality.

In a Japanese study[1], the combined effect of noise, lighting and thermal conditions was investigated. But, as no direct comparison between these parameters was made, the study was inconclusive in determining the relative importance of any given parameter.

Therefore, the purpose of the study by the Technical University of Denmark was to determine the relative importance of sensory air pollution, noise and thermal loads on human comfort by direct comparison of the individual parameters.

The research plan

The research used the indoor air quality and thermal comfort theories devised by Professor Ole Fanger[2,3]. Indoor air quality measurements used Fanger's sensory units, the olf and decipol. Fanger's thermal comfort equation is derived from quantifying clothing level (clo) and metabolic rate (met).

Experiments were performed in two identical environmental chambers, A and B. In the first part of this investigation (which centred on experiments 1 to 7), different combinations of thermal load and sensory air pollution in chamber A were sequentially compared with a range of noise levels in chamber B.

In the second part of the investigation (which included experiments 8 to 10), different levels of sensory air pollution in chamber A were sequentially compared with a range of thermal loads in chamber B. The levels of thermal load and sensory air pollution were selected to correspond to 10, 20, 40 and 60% persons dissatisfied (ppd).

The corresponding values of operative temperature and perceived air quality are listed in table 1. A similar relation between noise level and percentage dissatisfied was not available from the literature.

For determination of the operative temperatures, the subjects were estimated to have a metabolic rate of 1·6 met, and to wear clothing with an insulation of 1 clo.

Sensory assessments

A panel comprising eight men and eight women performed the sensory assessments. All subjects passed a selection test to ensure that they had normal auditory, olfactory and chemical senses. Instruction in the use of questionnaires was the only training given to the panel members.

The study was performed in two identical, adjacent environmental chambers[4]. In each chamber, a curtain was used to hide the sound generating equipment and the sources of air pollution.

The noise used in the experiments was road traffic noise. A two-minute recording of this was repeatedly played back through speakers in the chambers.

In chamber A the sound level was adjusted to maintain a constant A-weighted equivalent sound pressure level L_{Aeq} of 40 dB. This was then considered to be the background level.

A calibrated attenuator was installed so that the sound pressure level (spl) in chamber B could be varied between 40 and 75 dB in steps of 5 dB.

A mixture of carpet, rubber, fresh paint and cigarette butts was used to generate air pollution in chamber A. Different amounts of the mixtures of materials were used to obtain the desired levels of perceived air quality.

Test procedure

In experiments 1 to 7, a given combination of thermal load and sensory air pollution in chamber A was compared to eight noise levels in chamber B, with the spl ranging from 40 to 75 dB.

Operative temperatures in chamber A ranged between 21·3°C and 28·4°Cn and perceived air quality between 0·6 and 8·9 decipol. The noise levels in chamber B were presented in random order. The comparison was made after a one-minute exposure in each of the two environmental chambers.

The subjects were asked to evaluate the conditions in each chamber and to compare them. They did this by filling in questionnaires. The first question was: 'Imagine that during your daily work in an office you experienced the same air quality, noise and temperature as in this chamber. How annoying do you find these conditions?'

The scale employed for answering this question was a continuous annoyance scale, ranging from 'no annoyance' to 'slight annoyance', then 'moderate annoyance', 'high annoyance', 'very high annoyance' and 'overpowering annoyance'.

The second question was: 'Do you think that the conditions in this room are

Table 1: Operative temperatures and perceived air quality corresponding to the selected levels of dissatisfaction

Level of dissatisfaction (%)	Operative temperature (°C)	Perceived air quality (decipol)
10	21·3	0·6
20	23·3	1·4
40	26·0	4·1
60	28·4	8·9

A panel comprising eight men and eight women performed the sensory assessment. All subjects had to pass a selection test to ensure they had normal auditory, olfactory and chemical senses.

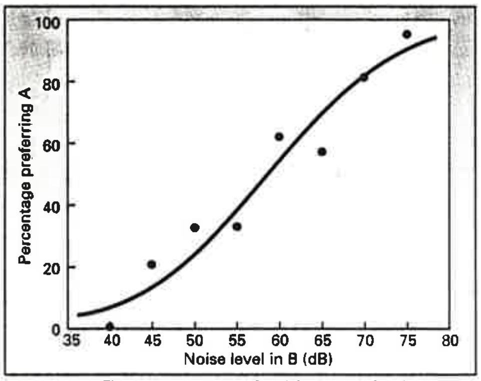

Figure 1: The percentage of subjects preferring chamber A as a function of the noise level in chamber B for experiment 5. Each point on the figure is the mean of 16 assessments.

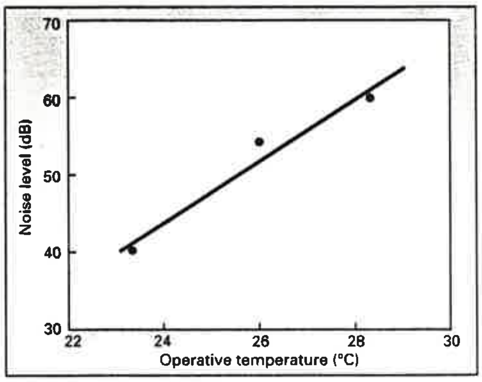

Figure 2: Noise levels in chamber B and operative temperature in chamber A resulting in equal preference for the two chambers.

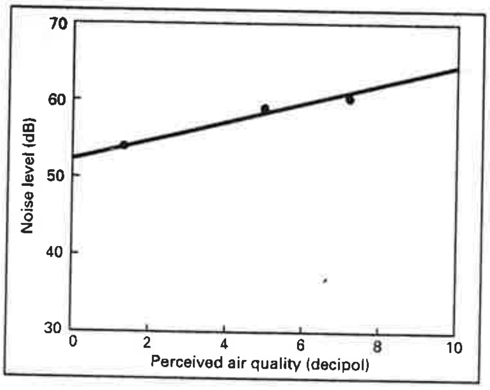

Figure 3: Noise levels in chamber B and perceived air quality in chamber A resulting in equal preference for the two chambers.

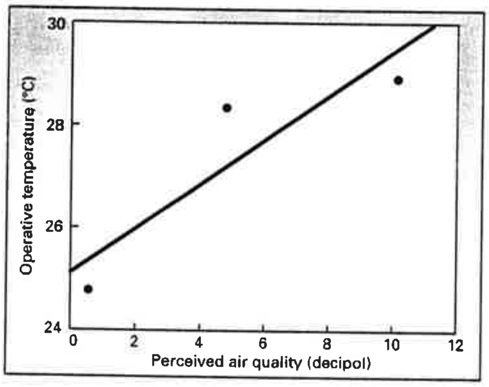

Figure 4: Operative temperatures in chamber B and perceived air quality in chamber A resulting in equal preference for the two chambers.

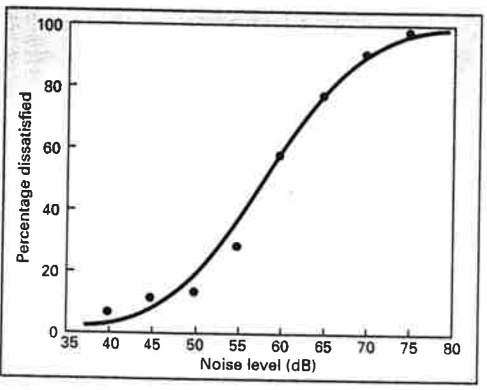

Figure 5: PPD as a function of traffic noise level. Data points represent the mean of 112 tests. The curve is the result of probit analysis.

acceptable for carrying out office work?' The scale used for this question was a continuous scale ranging from 'clearly acceptable' to 'clearly not acceptable'.

Once the subjects had answered the two questions for both chambers, they answered the final question: 'In which of the two chambers would you rather be?'

They answered this question by circling either chamber A or chamber B.

The final question of preference was answered when the subjects had left both chambers. When all eight noise levels in chamber B had been compared with the given environment in chamber A, the operative temperature and air quality in chamber A was altered and the next experiment started.

In experiments 8 to 10, a given level of sensory air pollution in chamber A was compared with four levels of operative temperature in chamber B.

Research findings

Figure 1 shows the relationship between the percentage of subjects preferring chamber A as a function of the noise level in chamber B for experiment 5.

The actual perceived air quality in chamber A was assessed to be 5·1 decipol, and the operative temperature 21·3°C (neutral). As the noise level in chamber B increases, the percentage of subjects preferring chamber A also increases.

Analysis revealed that at a noise level of 58 dB in chamber B, the panel displayed equal preference for the two chambers. Similar relationships were found for the other combinations of perceived air quality and operative temperature in chamber A.

Figures 2 and 3 show the noise levels in chamber B and operative temperature or perceived air quality in chamber A resulting in equal preference in the two chambers.

Figure 2 shows that a 1°C temperature change in a space with good air quality has, on average, the same effect on human comfort as a 3·9 dB change in noise level. Figure 3 shows that a change in perceived air quality of 1 decipol at neutral operative temperature has, on average, the same effect on human comfort as a 1 dB change in noise level.

Figure 4 shows the operative temperature in chamber B and the perceived air quality in chamber A resulting in equal preference for the two chambers.

The figure shows that a 1°C temperature change in spaces with low background noise level has, on average, an effect on human comfort equivalent to a change in perceived air quality of 2·4 decipol.

What the study reveals

The study allowed the subjects to evaluate the relative importance of poor indoor air quality, thermal load and noise without using any scales. The main results are based on simple preference statements from the subjects themselves.

The operative temperature turned out to be important compared with perceived air quality. A small change of 1°C in the operative temperature was found to have the same effect on human comfort as a considerable change of 2·4 decipol in the perceived air quality.

Noise also proved to be important, as a 1·2 dB change in the noise level had the same effect on human comfort as a 1·0 decipol change in perceived air quality.

The results reveal the relative importance of the three environmental parameters after one minute exposures to the different environments. Different results may be obtained with longer exposure time, for example introducing a full eight-hour working day. This would be an interesting subject for a future study.

The experimental design allowed the three environmental parameters to be compared one by one. However, one experiment – experiment 7 – was included to study the combined effect of more than one parameter.

In this experiment the combination of 28·4°C operative temperature and a perceived air quality of 8·9 decipol was compared with a range of traffic noise levels. When tested individually, both environmental conditions had the same effect on human comfort as traffic noise with L_{Aeq} equal to 60 dB.

When the two environmental stressors were combined, the equivalent noise level was found to be 71 dB. Interestingly, this increment of 11 dB corresponds approximately to a subjective doubling of the loudness.

An interesting additional result of the study was the establishment of a relation between noise level and percentage of people dissatisfied (figure 5).

The relation is only valid for traffic noise, and is based on the unadapted impression (one minute exposure). The percentage of people dissatisfied is given by:

$$4.35\int_{-\infty}^{\text{noise level}} \exp\left(-\left(\frac{x-58.6}{13.0}\right)^2\right)dx$$

The final analysis

In spaces with good air quality and with operative temperature in the range of 23°C to 29°C, a 1°C change in the operative temperature was found to have the same effect on human comfort as a change of 2·4 decipol in the perceived air quality or a change of 3·9 dB in the noise level.

At neutral temperature, and for levels of perceived air quality up to 10 decipol, a 1 decipol change in perceived air quality had the same effect on human comfort as a change of 1·2 dB in noise level.

This article is based upon research carried out at the Technical University of Denmark by Geo Clausen, Linda Carrick, Professor Ole Fanger, Sun Woo Kim, Torben Poulsen and Jens Holger Rindel.

References

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