Modelling of Occupants' Subjective Responses and Indoor Air Quality in Office Buildings

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Introduction

The results of indoor air quality surveys have showed that it was quite easy to fulfil the requirements of indoor climate standards and recommendations, even in office buildings where the workers experienced sick building symptoms, and complained that the reason for their symptoms was poor indoor air quality (1, 2). Many researchers consider that psychosocial factors may serve as moderators or mediators in the sick building syndrome process, either increasing or decreasing the vulnerability of the individual to environmental exposures (3, 4).

A multidisciplinary approach is needed because it is obvious that psychosocial factors influence the perceived indoor air environment (5).

Objective

The objective was to study the dependencies of human perception of indoor air quality on physical and chemical quantities as well as various psycho-social background factors.

Materials and Methods

Buildings and Occupants

The study was performed in five office buildings (A, B, C, D and E). Personal temperature control was used at least partly in buildings A, C and E. Humidification of supply air was possible in buildings B and E. Cooling of supply air was used in buildings A, B and C. In buildings B and C (1. storey) variable air volume (VAV) was used and in all other buildings constant air volume (CAV) was used. The lower limit value of the designed supply air flow rate per person was equal in buildings A, B and C. For building E, however, the value was much higher, around 30 l/s; and for building D clearly lower, around 10 l/s .

Measurements and Data Acquisition

Data were acquired using real time indoor air quality monitoring and an Internet questionnaire survey (6, 7). Four computer-controlled data acquisition units collected physical and chemical parameters of the indoor air and the air conditioning system. The following sensors were connected to the system: temperatures, relative humidity, air velocities, carbon dioxide, multi-gas monitor (Brüel &Kjær 1302) for TVOC and CO and air pressure.

In each building the indoor air quality measurements and questionnaire survey were carried out in a one-month period during each season: winter, spring, summer and autumn. A detailed questionnaire was completed by the participants at the beginning of each period. This background questionnaire survey was based partly on the Swedish Örebro Questionnaire and the Finnish Occupational Stress Questionnaire. In addition, each day the participants completed a short daily questionnaire covering transient sensations.

Hierarchical Bayesian Model

Apparently, the questionnaire data has a hierarchical structure. The data were collected from a number of occupants most of whom have provided more than one response. We assumed that each individual has their characteristic sensitivity to different aspects of indoor air factors. In addition, there may be individual differences in the ways that the occupants transform their perceptions into questionnaire responses.

Based on these assumptions, we constructed the hierarchical model which is shown in Figure 1 (8). On the right hand side, all the measurements are combined into a single indicator variable, which is supposed to optimally describe the perceived temperature satisfaction (or air quality/ moisture satisfaction/draught). This variable is a deterministic function of the measurements. It is compared to two threshold values which depend on questionnaire variables and two different random components. The occupants changes his/her response whenever the value of the indicator variable crosses one of the two threshold values. On the left hand side, the factors which describe the long term and transient psychosocial environment and well-being are transformed via a linear function into two values which are meant to approximate the response threshold values. If the measurements and questionnaires contained enough information to explain all the responses, the model would be complete once the function parameters had been estimated. Obviously this was not the case and that is why random components must be added to these deterministic values in order to make them fit the data. We assumed that the questionnaire data would not explain all the individual differences. That is why we use occupant specific random constants, which are more informative than non-systematic random variables. We still need non-systematic random variation as well to make all the samples fit.

We estimated the parameters of the model using Bayesian Markov chain Monte Carlo methods (9). These methods, along with the hierarchical structure of certain variables of the model, very effectively prevent the model from being overfitted, even though the model may contain more than a hundred parameters.

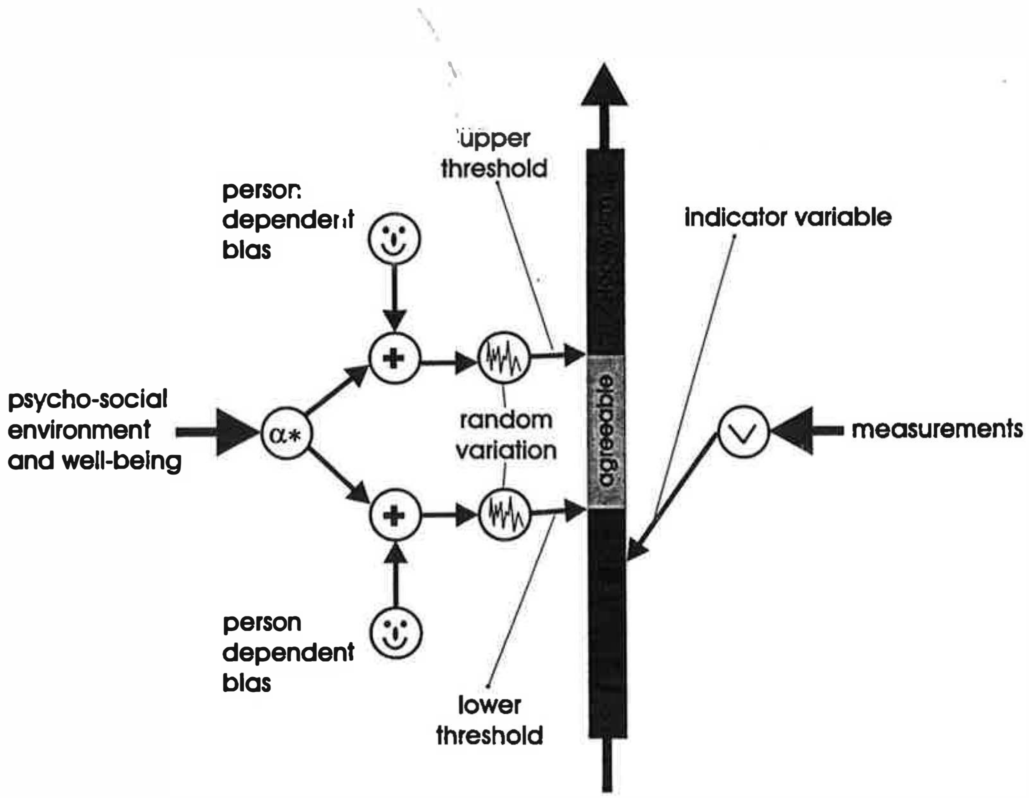

Figure 1. A hierarchical Bayesian model to explain temperature satisfaction. The measured conditions are compared with the two threshold values depending on psychosocial variables, occupant spesific and non-systematic random variables.

Results

In 1997-1999 there were 710 responders to the background questionnaire and 5 786 to the daily form. It was possible to connect the measurement data to 639 questionnaire responses from 109 different individuals.

The range of the measured values was not wide (Table 1). 44 % of the measurement-questionnaire-pair records showed dissatisfaction to draught, 32 % to thermal conditions, 24 % to dryness of air and 10 to stuffy air quality. Those occupants who had possibility to adjust the temperature personally were more satisfied with thermal conditions, but complained two times more of air dryness and staffiness.

Table 1. Summary of the measurement results.

	Mean value±standard deviation
Temperature at neck level, °C	23,2±3,1
Temperature at ankel level, °C	22,7±2,7
Temperature difference between neck and ankel, °C	0,5±1,6
Relative humidity, %	30±13
Air velocity, m/s	0,07±0,08
Carbon dioxide, ppm	480±100

According to the hierarchical Bayesian model only measured temperature had a significant relationship with the subjective temperature satisfaction and air quality. Figure 2 shows an example of the results obtained by the model.

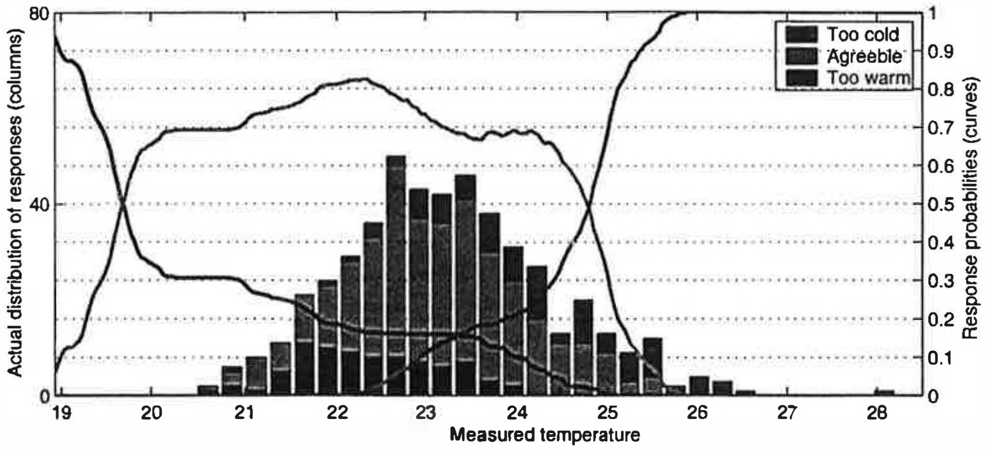

Figure 2. Bars represent the actual distribution of temperature satisfaction and curves represent estimates for the probabilities of different responses as a function of measured air temperature. Other measured factors were excluded from this example because they were found to be related only slightly to the responses. The effect of psychosocial factors have been averaged out.

Psychosocial factors explained 10 % of the variation in the threshold values. Individual differences in sensitivity (occupant spesific random variable) explained 55 % and 40 % of the variation in the threshold values for thermal satisfaction and air quality, respectively. Random variables explained 20 % and 50 % of the variation in the threshold values for thermal satisfaction and air quality, respectively.

Conclusions

Only temperature of the measured variables had a significant relationship with the subjective temperature satisfaction and air quality. The contribution of the other measured variables was practically insignificant. We can conclude that the temperature adjustment can be adapted according to the feedback received from the occupants, because unexpected random factors cover only 20 % of the variation in threshold values. Instead of that, in the case of air quality random factors have a more significant role (50 %) in the variation of the threshold values, which makes it difficult to get the contol system to adapt according to the feedback from occupants.

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