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A multivariate-logistic model for acceptance of indoor environmental quality (IEQ) in offices

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Abstract

The indoor environmental quality (IEQ) in offices is examined from the prospect of an occupant's acceptance in four aspects: thermal comfort, indoor air quality, noise level and illumination level. Based on the evaluations made by 293 occupants of the IEQ of offices in Hong Kong, empirical expressions have been proposed to approximate an overall IEQ acceptance of an office environment at certain operative temperature (T_o), carbon dioxide concentration (CO_2), equivalent noise level (L_{eq}) and illumination level (lux). The overall IEQ acceptance is calculated from a multivariate logistic regression model. A range of acceptance in typical office environmental conditions and its dependence on the four parameters stated above are determined for design conditions. The proposed overall IEQ acceptance can be used as a quantitative assessment criterion for an office environment and similar environment where an occupant's evaluation is expected.

Keywords: Indoor environmental quality; Multivariate logistic regression; Field survey; Air-conditioned offices

1. Introduction

Today the concept of an acceptable indoor environmental quality (IEQ) as an integral part of the total building performance approach is still not fully appreciated. Physical environmental parameters such as air temperature, relative humidity, acoustics, air quality, lighting, ventilation and air distribution are all interrelated, and the feeling of comfort is a composite state of an occupant's mind responding to the senses to these factors [1–4]. This state of mind is an intricate response to the indoor environmental factor groups, including physical environment sustained by the building and its services system, and individual physiological conditions such as health, social relations, financial state, etc.

Studies showed that an occupant's acceptance of an environment depended on a number of environmental parameters [5]. Four basic components, namely thermal comfort, indoor air quality, aural and visual comfort were identified for determining an acceptable IEQ. Conventional studies on indoor environment address each of them separately. They are still addressed independently by designers for many office designs. More recently, the equivalence of the discomfort caused by different physical qualities has been considered [6–8]. Discomforts caused by indoor air pollution, thermal load and noise were investigated. It was reported that at an operative temperature between 23 and 29 °C, each degree Celsius change would associate the same effect on human comfort with a change in perceived air quality of 2.4 decipol, or a change in noise level of 3.9 dB [7]. For levels of perceived air quality up to 10 decipol, a unit change had the same effect on human comfort as a change in noise level of 1.2 dB [6]. The equivalence of acoustic sensation to the thermal one was proposed for short-term exposure that each degree Celsius change in temperature had the same effect of 2.6 dBA [8]. Workplace variables inducing the largest number of health symptoms, comfort or odour concerns were investigated by multivariate regression analysis [9–15]. It was realised that successful control of the indoor

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environment required an understanding of the integral indoor environmental parameters. An overall IEQ index would be derived to describe the state of mind of a user in balance with the indoor environment.

Unacceptable indoor environments are often manifest in some forms and symptoms of sick building syndrome (SBS) prevail in many office buildings [11]. This study argues that the subjective evaluation of an indoor environment being perceived by an occupant can be used to assess the acceptance of the IEQ. In particular, occupants' acceptance of the four basic components of IEQ was evaluated and correlated with the overall IEQ acceptance of an office environment. The occupants' attitudes towards the operative temperature, CO_2 concentration, equivalent noise level and illumination level and the overall IEQ acceptance recorded by a dichotomous scale were studied [5,16–18]. Mathematical expressions were proposed for the overall IEQ acceptance using a multivariate logistic regression model with the former four parameters recorded. The proposed overall IEQ acceptance can be used as a quantitative assessment criterion for an office environment and similar environment where an occupant's evaluation is expected.

2. Methodology

Subjective evaluations made by 293 occupants of indoor environmental conditions in typical air-conditioned offices in Hong Kong were studied. The sample offices had floor areas ranged from 90 to 1200 m^2 and covered Grades A–C offices in Hong Kong, where, *Grade A* offices were spacious and furnished with high-quality finishes, flexible layout, large floor plates, well decorated lobbies and circulation areas, effective central air-conditioning, good lift services zoned for passengers and goods deliveries, professional management, and parking facilities were normally available; *Grade B* offices were of ordinary design with good-quality finishes, flexible layout, average-sized floor plates, adequate lobbies, central or free-standing air-conditioning, adequate lift services, good management, and parking facilities were not essential; and *Grade C* offices were those plain with basic finishes, less flexible layout, small floor plates, basic lobbies, hardly any central air-conditioning, barely adequate or inadequate lift services, minimal to average management and no parking facilities.

The occupant's acceptance of the perceived indoor environment given by four aspects, namely thermal environment, indoor air quality, equivalent noise level and illumination level, was studied with a dichotomous assessment scale [19]. This scale was used for a direct feedback of acceptability with the question 'Is the thermal environment/indoor air quality/noise level/illumination level being perceived in the office environment acceptable to you?' being asked. The ranks '(1) Yes, acceptable' and '(0) No, not acceptable' were self-explanatory. In order to confirm the validity of their responses, each respondent had to use a semantic differential evaluation scale for the subjective assessment of the first two aspects, and a visual analogue assessment scale for the evaluation of the aural and visual comfort [19]. At the end of the survey, an overall acceptance of the IEQ was determined.

3. Overall acceptance of IEQ

For a typical local office environment being perceived by an occupant, this study suggests the overall IEQ acceptance θ is dependent on four environmental parameters, namely the operative temperature ζ_1(°C), the CO_2 concentration ζ_2 (ppm), the equivalent noise level ζ_3 (dBA) and the illumination level ζ_4 (lux),

$$\theta = f(\phi_i); \quad i = 1, \ldots, 4, \tag{1}$$

$$\phi_i = \phi_i(\zeta_i); \quad i = 1, \ldots, 4, \tag{2}$$

where ϕ_i is the level of acceptance of the four environmental factors.

The level of acceptance of a thermal environment ϕ_1 at certain operative temperature ζ_1 is related to the predicted percentage dissatisfaction (PPD) of thermal comfort [17,20],

$$\phi_1 = 1 - \frac{\mathrm{PPD}}{100}. \tag{3}$$

From a recent study for 61 typical offices in Hong Kong, the percentage acceptance of indoor air quality ϕ_2, aural environment ϕ_3 and illumination level ϕ_4, given ζ_2, ζ_3 and ζ_4 at working plane, is correlated by Mui and Wong [21–23]:

$$\phi_2 = 1 - \frac{1}{2}\left(\frac{1}{1+\exp(3.118 - 0.00215\zeta_2)} - \frac{1}{1+\exp(3.230 - 0.00117\zeta_2)}\right); \quad 500 \leqslant \zeta_2 \leqslant 1800, \tag{4}$$

$$\phi_3 = 1 - \frac{1}{1+\exp(9.540 - 0.134\zeta_3)}; \quad 45 \leqslant \zeta_3 \leqslant 72, \tag{5}$$

$$\phi_4 = 1 - \frac{1}{1+\exp(-1.017 + 0.00558\zeta_4)}; \quad 200 \leqslant \zeta_4 \leqslant 1600. \tag{6}$$

4. Result and discussion

The surveyed office environmental conditions were typical, i.e. the operative temperature ζ_1, the carbon dioxide concentration ζ_2, the equivalent noise level ζ_3 and the illumination level ζ_4 at working plane were 18–25 °C, 500–1800 ppm, 45–72 dBA and 200–1600 lux, respectively [5].

A total of 293 occupants were interviewed and their evaluations of the IEQ and the four parameters were obtained. The results are summarized in Table 1. The correlation between subjective response to each parameter