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How does occupant perception on specific IEQ factors affect overall satisfaction?

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Abstract

This study aims to develop a better understanding of the relationship between the perceived performance of specific IEQ factors and occupants' overall satisfaction with their workspace, based on the hypothesis that the impact of an IEQ factor can differ depending on whether or not the occupants were satisfied with the IEQ factor in question. That is, a certain amount of increase or decrease in an IEQ factor's perceived performance does not necessarily translate into commensurate increment or decrement in occupants' overall satisfaction. Multiple regression analysis was conducted on the POE database from CBE (Center for the Built Environment) to estimate the impact of 15 different IEQ factors on overall satisfaction, depending on whether the performance on each IEQ factor was satisfactory or not. The results indicated that about half the IEQ factors had asymmetric effects on overall occupant satisfaction; these factors had a predominantly negative impact on overall satisfaction when occupants perceive that the building underperformed or was deficient in some way.

Keywords

Indoor environmental quality, Occupant satisfaction, Office workspace, Post-Occupancy Evaluation

1. Introduction

The topic of Indoor Environmental Quality (IEQ) seems to be generating increased research activity in response to growing awareness of the significance of IEQ issues to office-based workforces, and the linkage of sick building syndrome to poor IAQ (e.g. Jones, 1999; Wargocki, 2000; Fisk, 2000) has served to heighten this awareness. Apart from health issues, some researchers justify indoor environment research by noting that human resources account for the largest proportion of total expenses in the life cycle of a building (e.g. Pyke et al., 2010; Kats et al., 2003). Occupants who are satisfied with the overall environmental quality of their workspace are widely assumed to be more productive (e.g. Leaman and Bordass, 2007; Humphreys and Nicol, 2007). In addition, it seems that occupants are being regarded like consumers of the product (building) and as such, entitled to be satisfied with the indoor environmental product. Consequently, more research works dealing with building occupant satisfaction are being conducted than ever before. Finally, the adoption of occupant satisfaction surveys in the IEQ section of building sustainability rating

schemes such as LEED (USGBC, 2009) and NABERS (NABERS, 2010) has sharpened the focus on how occupants perceive and use buildings.

A number of studies have attempted to understand the quantitative relationship between occupant overall satisfaction and the building's performance on individual IEQ factors such as thermal comfort, acoustic quality, air quality and visual comfort, primarily to find out which has the most significant effect on occupant satisfaction. Based on a comprehensive literature review, Frontczak and Wargocki (2011) report that thermal comfort is slightly more important than other IEQ factors. However Fig. 1 indicates that this finding was not universally consistent across all research papers on this question (Frontczak and Wargocki, 2011). Some researchers remain sceptical because myriad confounding factors can potentially distort the relationships between occupant satisfaction and IEQ factors (Leaman and Bordass, 2007; Bluysen, 2010). It is becoming clear that increases in occupants' overall satisfaction do not correspond uniformly to improvements of individual IEQ factors (Humphreys, 2005; Bluysen et al., 2011). Some researchers argue that studies into occupant satisfaction need to take account of wider, contextual factors such as personal, situational and social factors, each of which may affect occupants' overall satisfaction with their building (Bluysen, 2010; Brown and Cole, 2009). Nevertheless there has been no previous research on the nature of the relationship itself: how does occupant overall satisfaction correspond to the building's performance on individual IEQ factors?

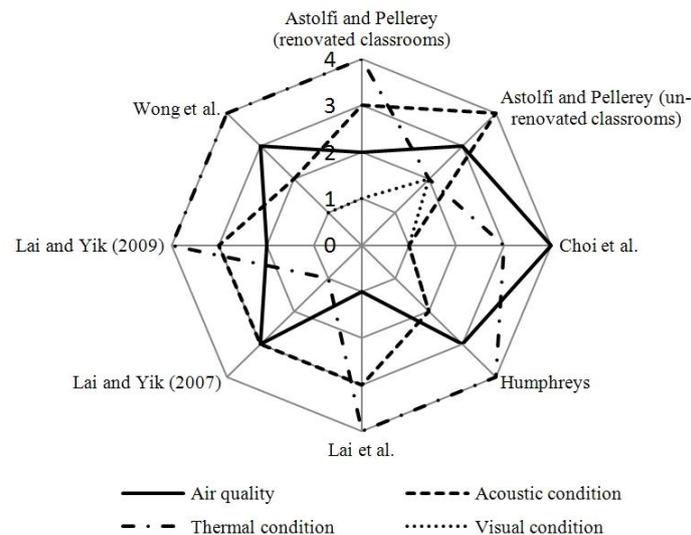


Fig. 1. Previous researchers' attempts at ranking (higher number indicates higher ranking) of importance of IEQ factors for overall satisfaction (Frontczak and Wargocki, 2011)

The question of defining the functional dependence of overall satisfaction upon a variety of individual properties is a generic one that can be found in many different disciplines. Marketing literature is replete with studies dealing with customer satisfaction and how it is influenced by specific properties or qualities of the product or service in question (Kano, 1984; Brandt, 1988; Matzler and Hinterhuber, 1998; Anderson and Mittal, 2000). In the discipline of marketing research, the relationship between customer satisfaction and the quality of a product or service has usually been assumed to be one-dimensional (Kuo, 2004; Lai and Wu, 2011), i.e. the level of customer satisfaction is linearly dependent upon product quality; the higher the

quality, the more the customers will be satisfied. However, when it comes to ‘satisfaction’, it does not always work as anticipated. In most instances, the relationship between the performance of a product and customer satisfaction is nonlinear and asymmetric (Anderson and Mittal, 2000). That is, a certain amount of increase or decrease of product quality does not necessarily translate into commensurate increases or decreases of satisfaction. Based on this argument, this study aims to identify nonlinear relationship between occupants’ overall assessment of the environment and the perceived performance of individual IEQ factors. Using a large Post Occupancy Evaluation (POE) database (Zagreus et al., 2004), an empirical test is performed on this hypothesis: *different IEQ factors affect occupants’ overall satisfaction in different ways: some linear and some nonlinear.*

2. Methods

2.1 Occupant survey sample: CBE’s database

Table 1. List of questionnaire items used for the analysis (from CBE occupant survey database)

IEQ Dimensions	Questionnaire items	Survey questions
Thermal comfort	Temperature	<i>How satisfied are you with the temperature in your workspace?</i>
Air quality	Air quality	<i>How satisfied are you with the air quality in your workspace (i.e. stuffy/stale air, cleanliness, odours)?</i>
Lighting	Amount of light	<i>How satisfied are you with the amount of light in your workspace?</i>
	Visual comfort	<i>How satisfied are you with the visual comfort of the lighting (e.g., glare, reflections, contrast)?</i>
Acoustic quality	Noise level	<i>How satisfied are you with the noise level in your workspace?</i>
	Sound privacy	<i>How satisfied are you with the sound privacy in your workspace (ability to have conversations without your neighbours overhearing and vice versa)?</i>
Office layout	Amount of space	<i>How satisfied are you with the amount of space available for individual work and storage?</i>
	Visual privacy	<i>How satisfied are you with the level of visual privacy?</i>
	Ease of interaction	<i>How satisfied are you with ease of interaction with co-workers?</i>
Office furnishings	Comfort of furnishing	<i>How satisfied are you with the comfort of your office furnishings (chair, desk, computer, equipment, etc.)?</i>
	Adjustability of furniture	<i>How satisfied are you with your ability to adjust your furniture to meet your needs?</i>
	Colours & textures	<i>How satisfied are you with the colours and textures of flooring, furniture and surface finishes?</i>
Cleanliness & maintenance	Building cleanliness	<i>How satisfied are you with general cleanliness of the overall building?</i>
	Workspace cleanliness	<i>How satisfied are you with cleaning service provided for your workspace?</i>
	Building maintenance	<i>How satisfied are you with general maintenance of the building?</i>
Overall satisfaction	Satisfaction with workspace	<i>All things considered, how satisfied are you with your personal workspace?</i>

The occupants’ survey database from CBE (Center for the Built Environment) at the University of California, Berkeley is used for the empirical test. CBE has conducted occupants’ survey since 2000 (Lee, 2010) and cumulated data from more than 600 buildings with various usages as of June 2010 (Frontczak et al, 2011). It is a web-based survey tool covering various IEQ dimensions such as thermal comfort, air

quality, lighting, acoustic quality, office layout, office furnishings, and cleanliness & maintenance (Zagreus et al., 2004). Occupants rate their satisfaction with IEQ parameters on a 7-point bipolar scale that is anchored at one end with “very satisfied” (+3), and “very dissatisfied” (-3) at the other end. These questions are followed by diagnostic questions if occupants indicate dissatisfaction with any aspect of their work environment. At the end of the questionnaire respondents are invited to rate their overall satisfaction with, and productivity impacts of all aspects of indoor environment considered in the questionnaire. Since this paper is focussed on the relationships between individual IEQ factors and overall satisfaction with occupant workspace, items on the CBE questionnaire evaluating occupant satisfaction have been extracted for our analysis; 15 items focused on satisfaction with individual IEQ factors and one item for estimating overall satisfaction with workspace (please see Table 1). Our analysis is based on a total of 43,021 respondent samples from 351 different office buildings within the CBE database. The sample buildings are broadly described as offices, but include educational, public administration and research organisations. The sample buildings are located in various climate zones in different countries, including Australia, Canada, Finland and USA (mainly in USA).

2.2 Data analysis: multiple regression with dummy variables

In order to examine the hypothesis that the impacts of IEQ factors on occupants’ overall satisfaction are different in association with a building’s performance on that IEQ factors (i.e. whether the performance is perceived satisfactory to occupants or not), subject samples are divided into three groups for each IEQ factors. Firstly, highly satisfied occupants with an IEQ factor (subjects who rated their satisfaction level with at highest two votes i.e. +3 and +2) were assigned to a satisfied group. Secondly, occupants highly *dissatisfied* with an IEQ factor (subjects who rated their satisfaction with the lowest 2 points i.e. -3 and -2) were assigned to a *dissatisfied* group. Finally, samples showing indifference to the IEQ factor (subjects who rated their satisfaction level in the middle of the scale i.e. -1, 0, and +1) were assigned to a reference group. The logic behind this sorting is directly comparable to that used by Fanger (1972) in his mapping from a 7-point scale of thermal sensation (known as PMV) onto a thermal satisfaction/*dissatisfaction* bifurcation (forming the basis of his Predicted Percentage Dissatisfied PPD index). The purpose of this classification is to examine the difference of overall satisfaction between the three groups.

Multiple regression with dummy variable has been selected to analyze the survey data; regression is frequently used on research questions aimed at identifying nonlinear relationships between attribute performance and overall satisfaction (Anderson and Mittal, 2000; Matzler et al., 2004a; Matzler et al., 2004b; Matzler and Sauerwein, 2002; Busacca and Padula, 2005). Three dummy variables were created per IEQ factor to represent ‘satisfied group’, ‘dissatisfied group’, and ‘reference group’. Then multiple regression analysis was conducted with ‘satisfaction with workspace’ (i.e. overall satisfaction) as the dependent variable, and the other 15 IEQ factors with dummy variables as independent variables. Therefore the regression analysis created two coefficients for each of the IEQ factors: one for ‘satisfied group’ to measure the impact when the condition of the IEQ factor was perceived to be good, and the other for the ‘*dissatisfied group*’ to measure the impact when the condition of the IEQ factor was perceived to be poor.

As defined in the regression equation (1), positive coefficients indicate the IEQ parameter increases overall satisfaction, i.e. it has positive impact on overall

satisfaction, and vice versa for negative coefficients. Furthermore, the absolute values of regression coefficients signify the strength of impact on overall satisfaction. Therefore differences in regression coefficients on a particular IEQ factor between the satisfied and *dis*satisfied groups can be used as a basis of examining the differential significance influencing occupant overall satisfaction depending on each IEQ factor's perceived performance level. For example, if the absolute value of a positive coefficient outweighs that of the negative coefficient, this IEQ factor is deemed to have a stronger impact on overall satisfaction when occupants are satisfied with the building's performance on that IEQ factor. Or, if the absolute value of a negative coefficient outweighs that of the positive coefficient, then this IEQ factor has stronger impact on overall satisfaction when the building is deemed to be performing poorly on that factor. Finally, if the two coefficients have broadly the same absolute value, which means that both negative and positive impacts are approximately equal.

$$OS = b_0 + b_{1, \text{factor}1} X_{1, \text{factor}1} + b_{2, \text{factor}1} X_{2, \text{factor}1} + \dots + b_{1, \text{factor}15} X_{1, \text{factor}15} + b_{2, \text{factor}15} X_{2, \text{factor}15} \quad (1)$$

OS: occupants' overall satisfaction score with workspace

b_0 : average of overall satisfaction score of reference groups

X_1 : dummy set for satisfied group of IEQ factors

X_2 : dummy set for *dis*satisfied group of IEQ factors

b_1 : regression coefficient for satisfied group (increase in overall satisfaction score associated with satisfaction on individual IEQ factor)

b_2 : regression coefficient for *dis*satisfied group (decrease in overall satisfaction score associated with *dis*satisfaction on individual IEQ factor)

3. Results

First of all, the assumption of data normality was confirmed by histogram and normal probability plot. Also, the database used for these multiple regression analyses was internally consistent, or reliable (Cronbach's Alpha = 0.89). The proportion of variance in overall satisfaction explained by the multiple regression model was 63% ($R^2=0.63$), so the resultant model provided useable predictive capability for occupants' overall satisfaction. Finally, the degree of multi-collinearity of each independent variable with the other independent variables was examined by using Variance Inflation Factor (VIF) as the measure. The range of VIF values of independent variables was 1.16 ~ 2.57 with an average value of 1.72, which are well below the commonly accepted threshold level (VIF > 5).

Regression coefficients resulting from the procedure described above are listed in Table 2. Two regression coefficients per IEQ factor are given; one to estimate the impact on overall satisfaction with workspace when a building's performance on that IEQ factor was deemed satisfactory, and the other coefficient estimates the impact on overall satisfaction with workspace when performance of the IEQ factor was regarded as generally unsatisfactory. Positive coefficients identify IEQ factors that increase overall satisfaction scores above the constant ($b_0=0.38$), while negative coefficients indicate that the IEQ factor decrements overall satisfaction. By substituting these regression coefficients into Equation (1), an overall satisfaction rating score can be estimated from a given set of IEQ factor scores. For example, when occupants are satisfied with their building's 'temperature', the overall satisfaction score increases by 0.12 from the reference group, thus the overall satisfaction score becomes 0.50 ($0.38+0.12=0.50$). When occupants are *dis*satisfied with their building's 'temperature' conditions, their overall satisfaction rating decreases by 0.21 making the total score to

0.17 (0.38-0.21=0.17). In this case, the decrement of overall satisfaction when a building performs poorly on ‘temperature’ is bigger than the satisfaction increment when a building performs well on ‘temperature’.

Table 2. Regression coefficients for each IEQ factor’s satisfied occupant group and dissatisfied occupant group ($R^2=0.63$ of regression model, significance level: * $P<0.01$, ** $P<0.001$)

	IEQ factors	Regression coefficients	
		Satisfied group	Dissatisfied group
	(Constant) = 0.38		
1	Temperature	0.12**	-0.21**
2	Air quality	0.16**	-0.19**
3	Amount of light	0.18**	-0.18**
4	Visual comfort	0.10**	-0.14**
5	Noise level	0.21**	-0.38**
6	Sound privacy	0.15**	-0.19**
7	Amount of space	0.43**	-0.78**
8	Visual privacy	0.19**	-0.44**
9	Ease of interaction	0.21**	-0.25**
10	Comfort of furnishing	0.18**	-0.23**
11	Adjustability of furniture	0.10**	-0.19**
12	Colours & textures	0.16**	-0.28**
13	Building cleanliness	0.10**	-0.08*
14	Workspace cleanliness	0.04*	-0.08**
15	Building maintenance	0.14**	-0.13**

According to this analysis, the IEQ factor that makes the biggest impact on overall satisfaction was ‘amount of space,’ in both positive and negative directions. Satisfaction with the amount of workspace available per individual increases the overall satisfaction score by 0.43, which makes the total score 0.81 (0.38+0.43=0.81). The overall satisfaction score drops to -0.40 (0.38-0.78=-0.40) when occupants are *dissatisfied* with the amount of space. Following the procedure from these two examples, occupants’ overall satisfaction can be predicted according to a building’s performance on each of the IEQ factors covered by the CBE post-occupancy evaluation questionnaire.

Fig. 2 illustrates both positive and negative impacts of the 15 individual IEQ factors on overall satisfaction using regression coefficients as the index. The unshaded bar represents the positive impact of each IEQ factor, increasing overall workspace satisfaction when that factor is deemed to be performing well, while the shaded bar represents strength of negative impact, decreasing overall workspace satisfaction. Thus the relative magnitudes of both positive and negative impacts on satisfaction resulting from IEQ factors are summarized in this figure. It is evident that under- and over-performance on many IEQ factors differ in the strength of impact on occupant overall satisfaction, signalling nonlinear or asymmetric relationship between overall satisfaction and some of the IEQ factors’ perceived performance. In effect the influence of individual IEQ factors depends on whether the factor in question is delivered at a satisfactory level or not. For example, when thermal performance (‘temperature’) exceeds occupants’ expectations, the impact on overall satisfaction is relatively low (regression coefficient = +0.12). However when occupants are *dissatisfied* with thermal performance, the strength of impact nearly doubled

(regression coefficient = -0.21). Thus the impact of ‘temperature’ on overall satisfaction is bigger when the performance fails to meet occupants’ expectations. Expressed another way, this finding suggests that thermal *dis*comfort has a stronger impact on overall satisfaction than thermal comfort.

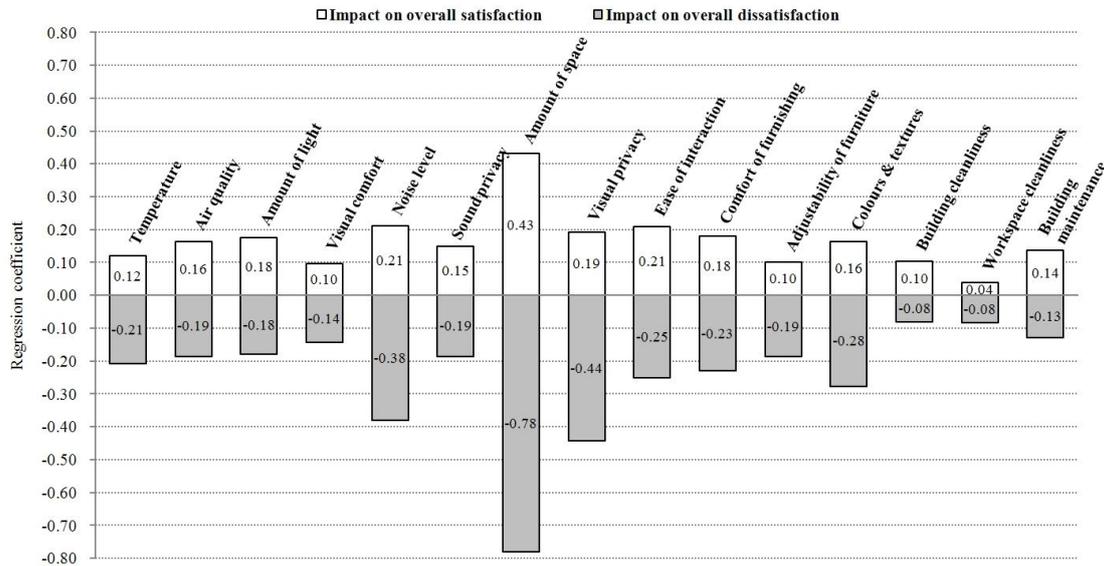


Fig. 2. Positive/negative impact of IEQ factors on occupant overall workspace satisfaction. The values attached to each bar represent regression coefficients for each IEQ factor’s satisfied occupants (unshaded bar) and dissatisfied occupants (shaded bar)

4. Discussion

There have been many previous attempts to identify the key IEQ factors associated with occupant overall satisfaction (e.g. Humphreys, 2005; Bluysen et al., 2011; Lee and Guerin, 2009; Lai and Yik, 2007). Table 3 ranks IEQ factors by their strength of impact on overall satisfaction (based on absolute value of the regression coefficients in Table 2). The left column gives ranking order for positive impacts and the right-hand column is for negative impacts. The rankings differ, depending on whether the performance of an IEQ factor is perceived to be satisfactory by occupants or not. That is, the impact of the IEQ factor changes depending on its perceived performance. Some IEQ factors tend to increase in their significance for overall occupant satisfaction when they are deemed to be inadequate, e.g. ‘visual privacy’ (from 4th to 2nd), ‘colours & textures’ (from 7th to 4th), and ‘adjustability of furniture’ (from 13th to 8th). Likewise, the importance of ‘temperature’ is ranked 11th out of the 15 factors when thermal conditions are deemed to be satisfactory, but its ranking increases up to 7th place when occupants deem thermal conditions to be unsatisfactory. This observation confirms what many Facilities Managers have long suspected; that building occupants don’t really care much about a building’s thermal comfort conditions unless they fall below occupants’ expectations.

This differential significance of impact in Table 3 implies that previous estimates of IEQ factor importance may have erred due to wrongly assuming linear relationships between all IEQ factors and overall satisfaction (Lai and Yik, 2007; Lai and Yik, 2009). For example, if a study reported low importance of thermal comfort (which increased its significance when performance was low in our analysis), it could be simply be an artefact of overall good thermal comfort conditions within the building

providing the data in that research study, leading to underestimation of the significance of thermal comfort. For example, in Fig. 1 we note that Lai and Yik (2007) reported that thermal comfort was perceived as the least important IEQ factor by building end-users. But when we scrutinise their survey data more closely, thermal comfort was rated positively in that particular building (mean rating between 5.0-5.3 points on their 7-point scale: 1='unacceptable', through 4='neutral' to 7='excellent'). The analysis in the present paper provides a fundamentally different interpretation of the Lai and Yik finding on thermal comfort; thermal comfort carries greater significance to overall occupant satisfaction when a building is deemed to be thermally uncomfortable. Had the Lai and Yik survey been conducted in a thermally uncomfortable building, the importance of thermal environment relative to other IEQ factors would probably have been rated higher.

Table 3. Ranking of IEQ factors for their impact on overall satisfaction depends on whether the building's performance on the IEQ factor meets occupant expectations or fails to meet them

Rank	When IEQ factor's performance is satisfactory	When IEQ factor's performance is <i>uns</i> atisfactory	Rank
1	Amount of space	Amount of space	1
2	Noise level	Visual privacy	2
3	Ease of interaction	Noise level	3
4	Visual privacy	Colours & textures	4
5	Comfort of furnishing	Ease of interaction	5
6	Amount of light	Comfort of furnishing	6
7	Colours & textures	Temperature	7
8	Air quality	Adjustability of furniture	8
9	Sound privacy	Air quality	9
10	Building maintenance	Sound privacy	10
11	Temperature	Amount of light	11
12	Building cleanliness	Visual comfort	12
13	Adjustability of furniture	Building maintenance	13
14	Visual comfort	Workspace cleanliness	14
15	Workspace cleanliness	Building cleanliness	15

Fig. 3 illustrates the differential significance of the IEQ factors that showed a nonlinear pattern of impact on overall satisfaction, depending on their perceived performance level (a criterion of 150% difference was set: IEQ factors with the negative impact outweighing the positive by more than 150%). The significance of these factors for overall satisfaction consistently increases when the building's performance on these factors is poor. This implies that when a building is performing well on these IEQ factors, they tend to go unnoticed. But when these IEQ factors are perceived to be inadequate and fail to meet occupant expectations, they can prompt significant overall dissatisfaction; they affect overall workspace satisfaction in a predominantly negative way. Unlike the IEQ factors in Fig. 3, the other IEQ factors (which fail to achieve a clear 150% positive or negative bias) did not show any clear tendency of differential impacts depending on the buildings' performance on those factors (see Fig. 4). That is, occupants' overall satisfaction level changed proportionally according to the perceived performance of those factors; increments or decrements of equal magnitude in the building's performance on those IEQ factors led to broadly similar magnitudes of enhancement, or diminution of overall workspace satisfaction.

Interestingly, there were no IEQ factors that clearly increased their significance when the performance of these factors was perceived to be excellent. It would seem as if

office environments are perceived and assessed in purely functional terms, and it is not easy to impress occupants with IEQ. However, before overgeneralising this to “no IEQ factors exert a significantly positive impact on occupant satisfaction”, it is important to remember that the CBE’s POE survey questionnaire used in this paper does not assess qualities such as aesthetics, daylighting or external views through windows, all of which could reasonably be expected to deliver ‘delight’ to occupants. Considering the fact that many of the green building rating tools around the world such as LEED (USGBC, 2009), BREEAM (BRE, 2010), and Green Star (GBCA, 2010) award “points” for the presence of natural lighting and external views, the absence of these factors from the analysis represents a limitation of this study.

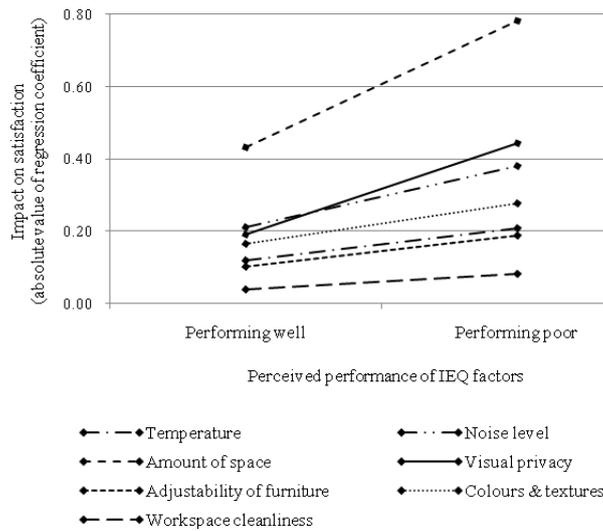


Fig. 3. IEQ factors showing different impacts on overall workspace satisfaction, depending on their performance being perceived positively or negatively.

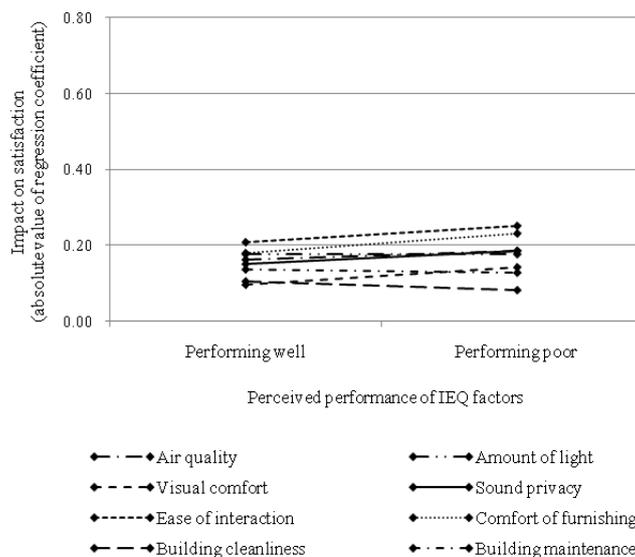


Fig. 4. IEQ factors showing no difference in their impact on overall workspace satisfaction, regardless of their performance being perceived positively or negatively.

5. Conclusions

By analyzing CBE's occupant survey database, this study identified the nonlinear relationship between IEQ factors and occupant overall satisfaction with workspace.

- First, 'temperature', 'noise level', 'amount of space', 'visual privacy', 'adjustability of furniture', 'colours & textures' and 'workspace cleanliness' showed differential significance on overall satisfaction. Their negative impact outweighs their positive effects on overall workspace satisfaction.
- Second, overall occupant satisfaction with workspace increases or decreases in linear proportion to the building's performance of following factors: 'air quality', 'amount of light', 'visual comfort', 'sound privacy', 'ease of interaction', 'comfort of furnishing', 'building cleanliness' and 'building maintenance'.

Everybody who makes resource allocation decisions for built environments, such as building managers, do so based on their own understanding of the relative significance of various dimensions of IEQ. It is important for them to know how different IEQ factors influence occupant satisfaction before rational priorities can be set, particularly when resources are constrained. Understanding the nonlinear relationship between different IEQ attributes and occupant overall satisfaction can potentially prevent inaccurate prioritization and sub-optimal resourcing of IEQ factors.

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