

# **Nonlinear relationships between individual IEQ factors and overall workspace satisfaction**

Jungsoo Kim<sup>1\*</sup>, Richard de Dear<sup>1</sup>

<sup>1</sup>Faculty of Architecture, Design and Planning, Wilkinson Building G04, The University of Sydney, NSW 2006, Australia

\*Corresponding author: Email: jungsoo.kim@sydney.edu.au, Phone: +61 2 9351 5605, Fax: +61 2 9351 3031

## **Abstract**

Despite a paucity of rigorous scientific evidence causally linking Indoor Environmental Quality (IEQ) issues to office occupants' productivity, there is a widespread belief that such causality exists; excellent or poor IEQ translate into productivity gains or losses respectively. The aim of this study is to better understand relationship between perceived building performance on specific IEQ factors and occupants' overall satisfaction with their workspace. Kano's satisfaction model, developed originally in the context of marketing, is adapted and tested for its suitability in the context of building occupants' satisfaction. Analyses were conducted on the occupant survey database from Center for the Built Environment (CBE) to estimate individual impacts of 15 IEQ factors on occupants' overall satisfaction, depending on the building's performance in relation to those IEQ factors. These empirical analyses identified nonlinearities between some IEQ factors and occupant satisfaction; some IEQ factors had a predominantly negative impact on occupants' overall satisfaction when the building underperformed. These have been labelled Basic Factors in the Kano Model of satisfaction and include 'temperature', 'noise level', 'amount of space', 'visual privacy', 'adjustability of furniture', 'colours & textures' and 'workspace cleanliness'. Other IEQ factors had a predominantly linear relationship with overall satisfaction – increments or decrements of equal magnitude in the building's performance on these factors lead to a broadly similar magnitude of enhancement or diminution of occupants' overall satisfaction. These were labelled Proportional Factors, and include 'air quality', 'amount of light', 'visual comfort', 'sound privacy', 'ease of interaction', 'comfort of furnishing', 'building cleanliness' and 'building maintenance'.

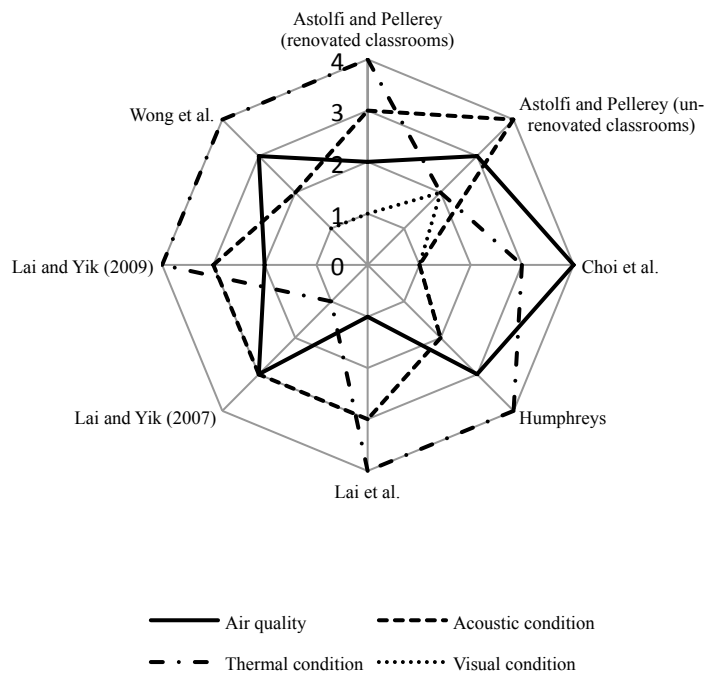
## **Keywords**

Indoor environmental quality, Occupant satisfaction, Kano's model, Office workspace, Building management, 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. [1-3]) 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. [4,5]). Occupants who are satisfied with the overall environmental quality of their workspace are widely assumed to be more productive (e.g. [6,7]). 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 (Leadership in Energy and Environmental Design) [8] and NABERS (National Australian Built Environment Rating System) [9] 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 [10] 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 [10]. Some researchers remain sceptical because myriad confounding factors can potentially distort the relationships between occupant satisfaction and IEQ factors [6,11]. It is becoming clear that increases in occupants' overall satisfaction do not correspond uniformly to improvements of individual IEQ factors [12,13]. 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 [11,14]. 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 [10])**

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 [15-18]. Kano [15] developed a model of customer satisfaction based on a classification of the type of relationship between specific product qualities and overall satisfaction. Different qualities or factors impact overall customer satisfaction in different ways: some in a positive way, some in a negative way, and some in both directions. The present study enquires whether Kano's customer satisfaction model is applicable in the context of building occupants and indoor environmental qualities, with a view to better understanding the relationship between overall satisfaction and the perceived performance on specific IEQ factors. The aim of this analysis is to prioritize various IEQ factors in a way that enhances the effectiveness of building management.

The structure of this paper is as follows: First, Kano's model of satisfaction is briefly described. Second, using a large Post Occupancy Evaluation (POE) database [19] an empirical test is performed on this hypothesis: *different IEQ factors affect occupants' overall satisfaction in different ways: some linear and some nonlinear*. Third, through statistical analysis, occupant overall satisfaction is

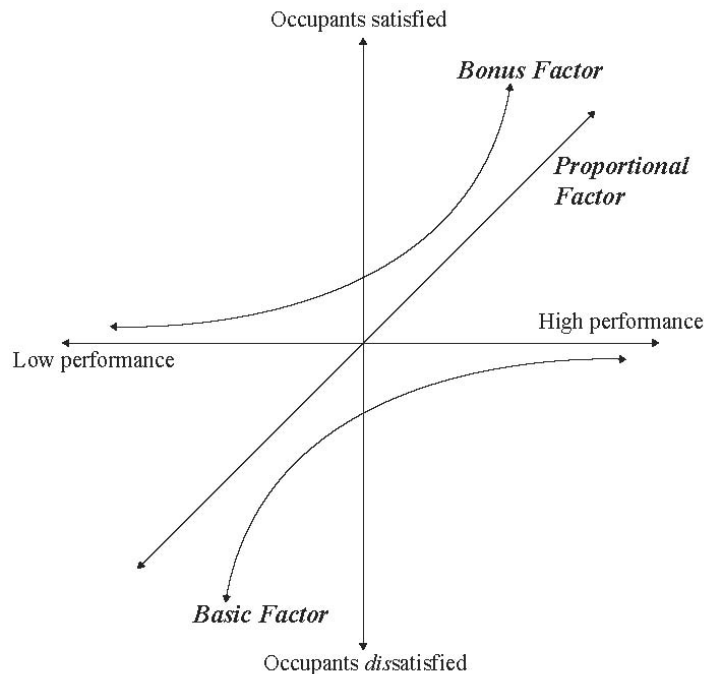
estimated and the IEQ factors are categorized with Kano's model. Finally, the implication of the study outcome for building management is discussed.

## 2. Kano's model of satisfaction

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 [20,21], 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 [18]. That is, a certain amount of increase or decrease of product quality does not necessarily translate into commensurate increases or decreases of satisfaction. Kano [15] categorizes product qualities according to the direction of their effect on satisfaction. This concept has been widely adopted in customer satisfaction research, and supported by various empirical tests [20-23]. Furthermore, Kano's model is extended to the studies examining employee satisfaction in an attempt to identify key factors affecting job satisfaction [24,25]. Adapting the Kano's satisfaction model to the building context, indoor environment quality factors can be classified into three categories: (1) Basic Factors (synonyms include "must-be," "expected," "satisfaction-maintaining" factors in the marketing literature), (2) Bonus Factors (synonyms include "excitement", "attractive", "value-added", and "satisfaction-enhancing" factors), and (3) Proportional Factors (synonyms include "performance" and "one-dimensional" factors). The aim of this paper is to examine if this nomenclature can be extrapolated to the specific context of building occupants' satisfaction with their workspace.

- *Basic Factors*: These can be thought of as minimum requirements. Occupants only notice this kind of factor if they are deficient or defective in some way. They don't necessarily enhance overall satisfaction but they can cause *dissatisfaction* when they are not fulfilled. Thus, the absolute magnitude of the impact resulting from under-performance is greater than the impact resulting from positive performance. Good performance on Basic Factors is a necessary (but not sufficient) condition for occupants' satisfaction.
- *Bonus Factors*: Bonus Factors go beyond minimum expectations, so when a product performs very well on Bonus Factors, there is a strong positive effect on occupant's satisfaction. However, poor performance on these factors doesn't necessarily result in *dissatisfaction*. So for Bonus Factors, the absolute value of the impact on overall satisfaction resulting from positive performance is greater than that resulting from under-performance.
- *Proportional Factors*: Occupant's satisfaction level changes proportionally according to the performance of these factors. When they perform well, occupants will be satisfied. And when

they perform poorly, occupants will be *dissatisfied*. Thus the relationship between occupants' overall satisfaction and the performance of Proportional Factors are linear.



**Fig. 2. Kano's satisfaction model (adapted from reference [15])**

Fig. 2 is a hypothetical graph illustrating the different nature of the relationship between occupants' overall satisfaction and these three different types of factors; Basic, Bonus, and Proportional. It shows nonlinear and asymmetric patterns effects of Basic and Bonus Factors on overall satisfaction, depending on their performance level. In the case of Basic Factors, underperformance has greater impact on overall satisfaction than equivalent increase of performance toward positive end of the scale. However, for Bonus Factors the impact on overall satisfaction levels resulting from excellent performance is much greater than the case when the building is performing very poorly on that factor. For the Proportional Factor in Fig. 2, however, a given increment (or decrement) in the building's performance on that factor is reflected by a constant, linear increase (or decrease) in occupants' overall satisfaction levels.

A logical extension of Kano's model is that these three types of functional relationships are dynamic; they can differ *between* market segments (i.e. group differences), and they can *change over time* [18,25]. To explain, the model should be responsive to changes in building occupants' expectations and different occupants respond in different ways to various aspects of indoor environmental conditions. That is, an IEQ factor regarded as minimum requirement (i.e. Basic Factor) for one group

of occupants could be a Bonus Factor for another group of people. For example, an occupant located in a spacious private office would have a higher expectation for indoor environmental quality than an occupant located in a dense, open-plan office. Similarly, the expectations of the same occupant could change as time goes by. That is, a factor regarded as Bonus Factor, for example view out of a window, could transform into a Proportional or even a Basic Factor as occupants become accustomed and take it for granted.

The research questions addressed in this paper include;

- Can Kano's model of customer satisfaction be generalized to the indoor environmental quality (IEQ) domain?
- Which of the IEQ factors (thermal comfort, air quality, lighting, acoustic quality, office layout and furnishings, and building maintenance) are Basic Factors, which are Bonus Factors, and which are Proportional Factors?
- Can Kano's satisfaction model be useful in the management of IEQ within the context of commercial buildings?

### **3. Methods**

#### **3.1 Occupant survey sample: CBE's database**

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 [26] and cumulated data from more than 600 buildings with various usages as of June 2010 [27]. 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 [19].

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).

**Table 1. List of questionnaire items used for the analysis (from CBE occupant survey database [19])**

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

### 3.2 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 their performance level (i.e. whether their performance is satisfactory to occupants or not), subject samples are divided into three groups for each questionnaire items. Firstly, highly satisfied occupants with an IEQ item (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 item (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 item (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 [28] 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.

The basic concept is as follows; when the group *dissatisfied* with IEQ item  $x$  reports significantly lower overall satisfaction in the workspace, but the other two groups show no difference for their overall satisfaction, then item  $x$  is classified as Basic Factor in Kano's nomenclature. That is, item  $x$  is only *dissatisfying* occupants. Second, when the overall satisfaction level of the satisfied group for IEQ item  $y$  is much higher than the other two groups, and the latter two groups have little difference, item  $y$  is categorized as Bonus Factor. That is, item  $y$  is only correlated to satisfying occupants. Third, if the satisfied group for IEQ item  $z$  shows higher overall satisfaction and the *dissatisfied* group shows lower overall satisfaction than the reference group, so all three groups are different, then item  $z$  is defined as Proportional Factor in Kano's nomenclature. That is, item  $z$  satisfies occupants when it performs well and *dissatisfies* occupants when it performs poorly. So the relationship of the item with overall satisfaction is unidimensional.

To analyze the survey data within Kano's satisfaction concept described above, multiple regression with dummy variables has been selected; regression is frequently used on research questions aimed at identifying nonlinear relationships between attribute performance and overall satisfaction [18,22,25,29,30]. Three dummy variables were created per questionnaire item and a binary coding applied; 0 and 1. Dummy coding is a method of representing different groups for statistical analysis. A dummy variable (coded 1, 0) was assigned to the 'satisfied group', another dummy variable with coding of 0, 1 was assigned to the '*dissatisfied* group', and the last dummy variable with coding of 0, 0 was assigned to the 'reference group'. This process was repeated across all 15 IEQ items. Based on this coding, multiple regression analysis was conducted with 'satisfaction with workspace' (i.e. overall satisfaction) as the dependent variable, and the other 15 items with dummy variables as independent variables. Therefore the regression analysis created two coefficients for each of the items: one for 'satisfied group' to measure the impact when performance of the IEQ item was good, and the other for the '*dissatisfied* group' to measure the impact when performance of the IEQ item was poor.

$$OS = b_0 + b_{1.item1}X_{1.item1} + b_{2.item1}X_{2.item1} + \dots + b_{1.item15}X_{1.item15} + b_{2.item15}X_{2.item15} \quad (1)$$

$OS$ : 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 items

$X_2$ : dummy set for *dissatisfied* group of IEQ items

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

$b_2$ : regression coefficient for *dissatisfied* group (decrease in overall satisfaction score associated with *dissatisfaction* on individual IEQ item)



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 item between the satisfied and *dissatisfied* groups can be used as a basis of identifying Bonus and Basic Factors under Kano's nomenclature. For example, if the absolute value of a positive coefficient of item *x* outweighs that of the negative coefficient, this IEQ is deemed to have a stronger impact on overall satisfaction when its performance is high (i.e. when occupants are satisfied with the performance on that IEQ item), thus item *x* is classified as Bonus Factor. Or, if the absolute value of negative coefficient on IEQ item *y* outweighs that of the positive coefficient, then item *y* falls into the Basic Factor category. Finally, if the two coefficients for item *z* have broadly the same absolute value, which means that both negative and positive impacts are approximately equal, then item *z* is classed as a Proportional Factor.

#### 4. 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 an 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 item are given; one to estimate the IEQ item's impact on overall satisfaction with workspace when performance on that IEQ item was deemed satisfactory, and the other coefficient estimates the impact of the IEQ item on overall satisfaction with workspace when performance of the IEQ item was regarded as generally unsatisfactory. Positive coefficients identify IEQ items that increase overall satisfaction scores above the constant ( $b_0=0.38$ ), while negative coefficients indicate that the IEQ item 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 *dissatisfied* 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

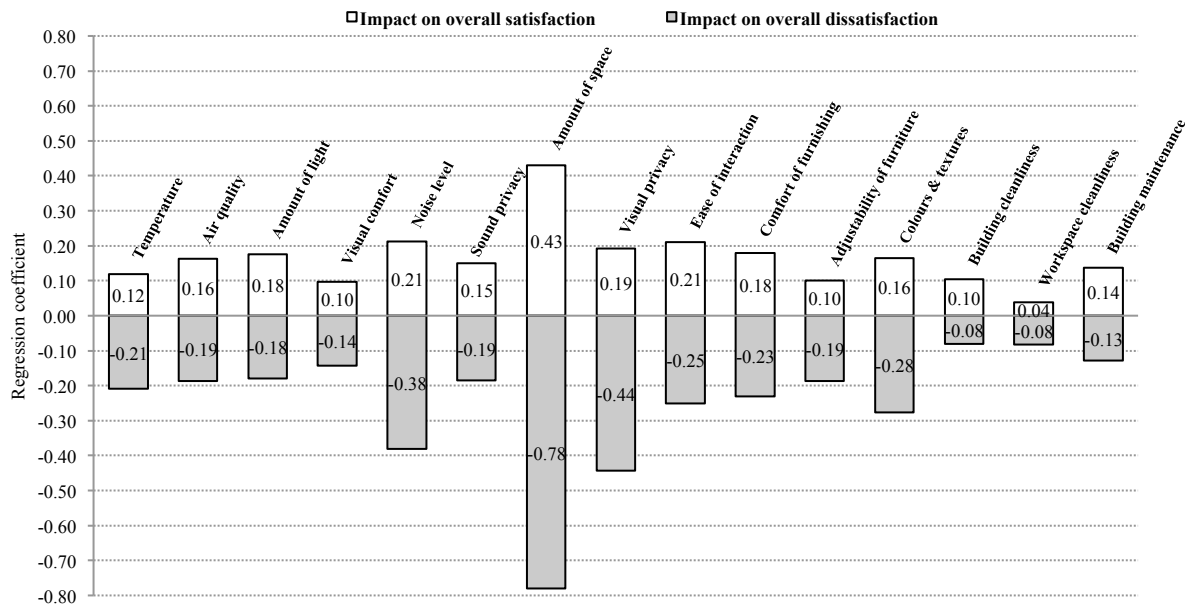
performs poorly on ‘temperature’ is bigger than the satisfaction increment when a building performs well on ‘temperature’.

**Table 2. Regression coefficients for each IEQ item’s satisfied occupant group and dissatisfied occupant group**

	IEQ items	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**

R<sup>2</sup>=0.63 of regression model, significance level of regression coefficients \*P<0.01, \*\*P<0.001

According to this analysis, the IEQ item that makes the biggest impact on overall satisfaction was ‘amount of space,’ in both positive and negative direction. 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. 3. 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 (white bar) and dissatisfied occupants (grey bar)**

Fig. 3 illustrates both positive and negative impacts of the 15 individual IEQ items on overall satisfaction using regression coefficients as the index. The upper part of the y-axis (positive region) represents the impact on overall satisfaction associated with high performance on the IEQ items, and the lower (-ve) part represents the strength of overall satisfaction impact associated with poor performance. Thus the relative magnitudes of both positive and negative impacts on satisfaction resulting from IEQ items are summarized in this figure. It is evident that under- and over-performance on many IEQ items differ in the strength of impact on occupant satisfaction, signalling nonlinear or asymmetric relationship between overall satisfaction and some of the IEQ factors' performance. In effect the influence of individual IEQ items depends on whether the item 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 *discomfort* has a stronger impact on overall satisfaction than thermal comfort. The item 'temperature', therefore, has the character of Kano's Basic Factors, as described in the earlier section of this paper.

The main discrepancy between this IEQ analysis and the model proposed by Kano is that all the IEQ factors have both positive *and* negative impacts on satisfaction, implying the possibility that even

Basic Factors can contribute to overall satisfaction to a certain degree, and also overall *dissatisfaction*, albeit modestly, if they perform below expectation. Previous applications of this classification technique in the marketing literature [25,29,30] were conducted with fewer than 200 survey samples, and so they probably were not concerned about the question of categorization since they typically had only one statistically significant coefficient, either positive or negative impact on the dependent variable, but not both. However, in the present study, both positive and negative regression coefficients for all IEQ items reached very high statistical significance (see Table 2) simply due to very large number of survey samples (n=43,021). This renders the task of sorting our IEQ items into either Basic or Bonus Factors on the basis of the sign of a singular, significant correlation coefficient problematic. Nevertheless, absolute magnitudes of many IEQ items' positive and negative impacts were clearly different (please see Fig. 3). For the purpose of using Kano's model to classify IEQ items into Proportional, Bonus and Basic groups, a criterion of 150% difference in +ve and -ve regression coefficients was set; if the positive impact of an item on overall satisfaction outweighs the negative by more than 150%, the item is classified as a Bonus Factor, and vice versa for Basic Factors. Items failing to achieve a clear 150% positive or negative bias default to the Proportional Factor category. Table 3 shows the categorization of all 15 IEQ items based on this 150% bias criterion. Seven Basic Factors were identified and the rest of IEQ items were classified as Proportional Factors. Interestingly no Bonus Factors were identified in this analysis.

**Table 3. Categorization of IEQ factors based upon Kano's satisfaction model**

Category	IEQ items
Basic Factors	Temperature, Noise level, Amount of space, Visual privacy, Adjustability of furniture, Colours & textures, Workspace cleanliness
Bonus Factors	None were identified in this analysis
Proportional Factors	Air quality, Amount of light, Visual comfort, Sound privacy, Ease of interaction, Comfort of furnishing, Building cleanliness, Building maintenance

## 5. Discussion

### 5.1 Applicability of Kano's model into IEQ domain

The first research question of this paper can now be addressed; "*Can Kano's model of customer satisfaction be generalized to the IEQ domain?*" The results of this analysis of the CBE Post Occupancy Evaluation (POE) database indicate that Kano's model generalizes successfully to the IEQ domain. Although no Bonus Factors were identified, some IEQ factors had a predominantly negative impact (Basic Factors) while the others had a linear relationship with overall satisfaction (Proportional Factors spanning both negative and positive impacts). The 15 IEQ factors extracted from the CBE database were successfully classified into distinct categories on the basis of the type of their relationship with occupants' overall satisfaction with their workspace. For Basic IEQ factors, the

same amount of increase or decrease in their performance resulted in different intensities of increment or decrement in occupants' overall workspace satisfaction. In contrast, Proportional IEQ factors can exert either negative or positive impacts of comparable intensity on occupant overall satisfaction, depending on whether the building meets or fails-to-meet occupants' expectations for that particular IEQ factor.

## **5.2 Different types of IEQ factors: how they influence on occupants' perception of satisfaction**

The second research question posed at the start of this paper was; "*Which of the IEQ factors are Basic Factors, which are Bonus Factors, and which are Proportional Factors?*" Application of the Kano's model of satisfaction to the CBE POE database identified 'temperature' and 'noise level' as Basic IEQ factors; when a building performs well on these factors and meets occupant expectations, the occupants' do not seem to notice and their overall satisfaction with the building remains unmoved. However, when a building's thermal and acoustic performance fails to meet occupant expectations, overall satisfaction levels are significantly eroded. In effect, thermal comfort and appropriate noise levels within the office workplace can be regarded as minimum requirements for building occupants. Air quality was classified as a Proportional Factor. Buildings perceived to have poor indoor air quality have noticeably lower overall occupant satisfaction ratings, while buildings perceived to have good indoor air quality have higher overall satisfaction ratings. When a building's lighting is perceived as comfortable (e.g. low glare, reflections, contrast) there is a positive improvement in occupant overall workspace satisfaction, while visual *dis*comfort exerts the opposite effect on overall satisfaction ratings. Therefore lighting condition within the office workplace has been assigned by this analysis to the group of Proportional Factors.

Interestingly there are several factors exerting noticeable impacts on occupants' overall satisfaction in this analysis that are usually ignored in the IEQ research literature. These included 'amount of space', 'visual privacy', 'adjustability of furniture' and 'colour & textures' (all Basic Factors), 'ease of interaction' and 'comfort of furnishing' (both Proportional Factors). All six of these IEQ factors are office layout and furnishing issues. Usually, thermal comfort, air quality, acoustic quality and visual quality (lighting) are featured prominently in the IEQ research literature, but office layout or furnishing issues rarely rate a mention.

IEQ factors related to cleanliness and maintenance ('workspace cleanliness', 'building cleanliness', and 'building maintenance') had relatively minor impacts on overall satisfaction (Fig. 3). It seems that cleaning service provided for individual occupant's space is deemed to be more essential ('workspace cleanliness': Basic Factor) than that of common area of a building ('building cleanliness': Proportional Factor).

There were no IEQ factors identified as Bonus by the analysis on CBE's POE database. Apparently none of the IEQ factors in this analysis deliver 'delight' to occupants of office buildings, and are more of accurately described in terms of 'must-have' rather than 'attractive.' It would seem as if office environments are perceived in purely functional terms and it is not easy to impress their occupants. However, before overgeneralising this to "no IEQ factors exert a significant 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 daylighting or external views through windows, both of which could reasonably be expected to be Bonus Factors. Considering the fact that many of the green building rating tools around the world (LEED [8], BREEAM [31], and Green Star [32]) 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.

### **5.3 Differential impacts of IEQ factors on overall satisfaction and the implications for building management**

There have been many previous attempts to identify the key IEQ factors associated with occupant overall satisfaction (e.g. [12,13,33,34]). Table 4 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 performance. Basic Factors tend to increase in their significance for overall occupant satisfaction when they are deemed to be inadequate. For example, the importance of 'temperature' is ranked 11<sup>th</sup> out of the 15 factors when thermal conditions are deemed to be satisfactory, but its ranking increases up to 7<sup>th</sup> 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 are below expectations. Likewise, the rank of other Basic Factors rose substantially, e.g. 'visual privacy' (from 4<sup>th</sup> to 2<sup>nd</sup>), 'colours & textures' (from 7<sup>th</sup> to 4<sup>th</sup>), and 'adjustability of furniture' (from 13<sup>th</sup> to 8<sup>th</sup>), when the building's performance on these factors was deemed to be unsatisfactory.

This differential significance of impact in Table 4 implies that previous estimates of IEQ factor importance may have erred due to wrongly assuming linear relationships between all IEQ factors and overall satisfaction [34,35]. For example, if a study reported low importance of thermal comfort (which we classified as a Basic Factor), 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 [34] reported that thermal comfort was perceived as the least important IEQ factor by building

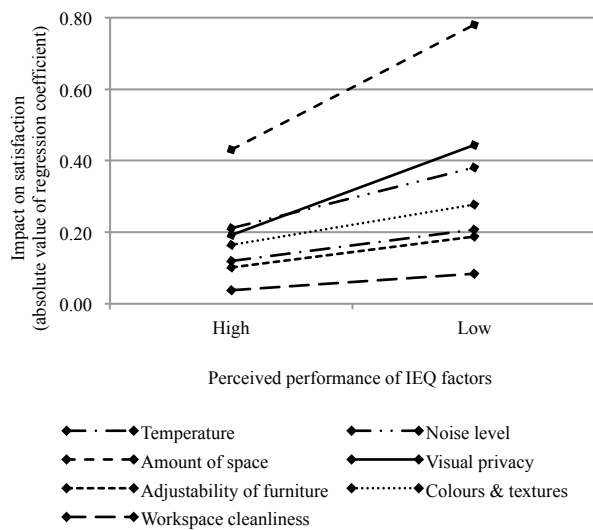
end-users. But when we scrutinise their survey data more closely, thermal comfort was rated positively in that particular building (mean rating between 5.0-5.3 points on their 7-point scale: 1=‘unacceptable’, through 4=‘neutral’ to 7=‘excellent’). The analysis in the present paper provides a fundamentally different interpretation of the Lai and Yik finding on thermal comfort; thermal comfort has bigger significance to overall occupant satisfaction when a building is deemed to be thermally uncomfortable.

**Table 4. 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**

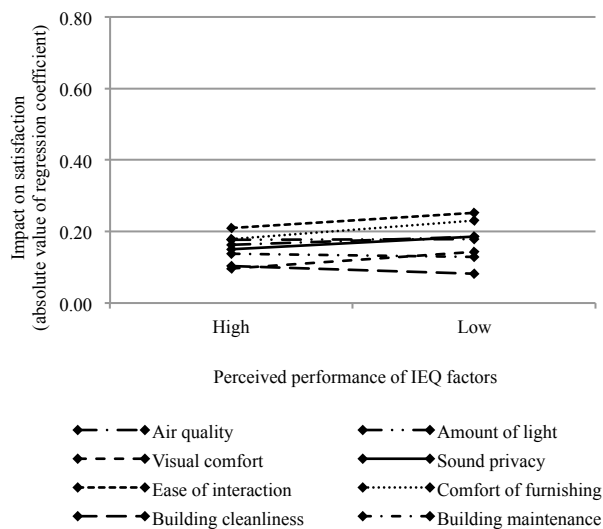
Rank	Perceived performance is high	Perceived performance is low	Rank
1	<i>Amount of space*</i>	<i>Amount of space*</i>	1
2	<i>Noise level*</i>	<i>Visual privacy*</i>	2
3	Ease of interaction	<i>Noise level*</i>	3
4	<i>Visual privacy*</i>	<i>Colours &amp; textures*</i>	4
5	Comfort of furnishing	Ease of interaction	5
6	Amount of light	Comfort of furnishing	6
7	<i>Colours &amp; textures*</i>	<i>Temperature*</i>	7
8	Air quality	<i>Adjustability of furniture*</i>	8
9	Sound privacy	Air quality	9
10	Building maintenance	Sound privacy	10
11	<i>Temperature*</i>	Amount of light	11
12	Building cleanliness	Visual comfort	12
13	<i>Adjustability of furniture*</i>	Building maintenance	13
14	Visual comfort	<i>Workspace cleanliness*</i>	14
15	<i>Workspace cleanliness*</i>	Building cleanliness	15

\*Basic Factors (the rest are Proportional Factors)

Fig. 4 illustrates the differential significance of Basic Factors on overall satisfaction, depending on their perceived performance level. The significance of Basic Factors for overall satisfaction consistently increases when the building’s performance on these factors is poor. This result is in line with what Astolfi and Pellerey [36] reported in their study comparing renovated and un-renovated classrooms for acoustical performance. They noted the strength of correlation between overall satisfaction and acoustic quality diminished when reasonable levels of acoustic quality prevailed (we classified ‘noise level’ as a Basic Factor). Unlike the Basic Factors in Fig. 4, Proportional Factors did not show any clear tendency of differential impacts depending on the buildings’ performance on those factors (please see Fig. 5).



**Fig. 4. Differential impact of Basic Factors on overall workspace satisfaction depending on their perceived performance**



**Fig. 5. Differential impact of Proportional Factors on overall workspace satisfaction depending on their perceived performance**

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. At the beginning of this paper our third research question was stated as; “*Can Kano’s model be useful in the management of IEQ issues within commercial buildings?*” Understanding the Kano model’s classification of



different IEQ attributes can potentially prevent inaccurate prioritization and sub-optimal resourcing of IEQ factors. For example, if thermal comfort is already being delivered at satisfactory levels, further investment would appear to be superfluous because overall occupant satisfaction levels will not be enhanced as anticipated (thermal comfort is a Basic Factor). Furthermore the incremental cost of thermal improvement is likely to rise at higher levels of performance (i.e. diminishing returns) [18]. To generalize, when all the Basic Factors of IEQ are already deemed by a particular building's occupants to be satisfactory, it is better to focus effort and resources on improving the Proportional and Bonus Factors. For example, improving the amount of light for office workers or enhancing interaction between colleagues with changed layout both represent more rational strategies to increase occupants' overall satisfaction levels than further investment in Basic Factors such as thermal environment when the latter are already deemed to be good enough.

## 6. Conclusions

By analyzing CBE's occupant survey database, this study identified the nonlinear relationship between IEQ factors and occupant overall satisfaction. And by employing Kano's model, IEQ factors are categorized into Basic Factors and Proportional Factors according to their influence on occupant satisfaction.

- First, 'temperature', 'noise level', 'amount of space', 'visual privacy', 'adjustability of furniture', 'colours & textures' and 'workspace cleanliness' were classified as Basic Factors. Their negative impact outweighs their positive effects on overall satisfaction, so it is important these factors are maintained at satisfactory levels.
- Second, 'air quality', 'amount of light', 'visual comfort', 'sound privacy', 'ease of interaction', 'comfort of furnishing', 'building cleanliness' and 'building maintenance' were classified as Proportional Factors. Overall occupant satisfaction increases or decreases in linear proportion to the building's performance of these factors.
- Third, no Bonus IEQ factors were identified. However, there is still the possibility of Bonus Factors because CBE's POE database does not cover all IEQ factors (notably daylighting, external view, and individual controllability of indoor environment).

This study was based on large number of post occupancy evaluation (POE) questionnaires (n=43,021) in 351 different office buildings with different ventilation types (naturally ventilated, air-conditioned and mixed-mode) across various climate zones and countries (Australia, Canada, Finland but mainly in USA). Survey respondents (age, gender, type of work, hours spent in the workspace) were very diverse. Therefore we believe the outcomes of this study apply to office buildings in general.

However, Kano's satisfaction model should deliver different classifications depending on expectation levels, which can be expected to vary through time and between groups. It might be useful to conduct

further research into how the categorization of IEQ factors changes according to the characteristics of occupancy, including occupant demographics, ventilation type (e.g. naturally ventilated, air-conditioned, mixed-mode), office type (e.g. cellular versus open-plan), etc. Such an analysis could identify specific requirements or expectations for different group of occupants.

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