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Kwon, Minyoung; Remøy, Hilde; van den Bogaard, Maartje

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Influential design factors on occupant satisfaction with indoor environment in workplaces

Minyoung Kwon[a,*], Hilde Remøy[b], Maartje van den Bogaard[c]

[a] Department of Architectural Engineering + Technology, Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands
[b] Department of Management in the Built Environment, Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands
[c] Department of Science Education and Communication, Faculty of Applied Sciences, Delft University of Technology, the Netherlands

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ABSTRACT

Occupant satisfaction with IEQ (indoor environmental quality) is influenced by many physical and psychological factors. This paper reports the results of a study that investigate influential office design factors on occupant satisfaction relating environmental dimensions such as thermal and visual comfort in workplaces and predicting which design parameters may bring better satisfaction to occupants. Five office cases in the Netherlands with 579 office occupants were studied using questionnaires, and interviews with facility managers and architects. Different statistical analysis tests were conducted to summarise satisfaction factors. Results show that 'desk location' and 'layout' contributed most to occupant's satisfaction with thermal and visual comfort regardless of seasons. In summer, 'orientation' was exceptionally considered as an important factor for satisfaction with thermal comfort. This study revealed that categorical and regression analyses are required to predict profound outcomes when the data are nominal and categorical variables. This study contributes to develop design solutions, which could improve occupants' environmental satisfaction in workplaces.

1. Introduction

User satisfaction in offices has been studied across disciplines such as social science, real estate, and building environment from different perspectives. The term 'user satisfaction' in the built environment has not been clearly defined. According to Cambridge dictionary, *satisfaction* is a pleasant emotion, when the expectations, or needs, are fulfilled or there is nothing to complain about. Frontczak et al. [1] reviewed 10 studies related to occupants' satisfaction and stated occupants' satisfaction is highly related to indoor environmental quality or to the workspace. Particularly, indoor environmental quality (IEQ) is one of the key issues for users' satisfaction. This is because occupants' satisfaction with environmental quality affect users' health and comfort perception [2]. For the reasons, users' perception and satisfaction of the space they use should be underscored in the built environment [2]. In addition, Samani [3] revealed that users' dissatisfaction normally comes from more than one ambient condition of the workplace. It also may come from composite physical workplace conditions such as location of their working desk, orientation of façade, cellular or open-plan layout, etc.

Despite of the importance of users' satisfaction in building performance, there are many problems in the built environment due to exclusion of the users' perspective. During the conceptual design phase of a building, many decisions are made based on the energy performance, indoor quality, and economic conditions, while the design phase has not adopted end-users' requirement and satisfaction because there is no standard principle and a lack of actual information about their requirements/needs [4]. Huber et al. [5] classified the number of publications dealing with criteria influencing user satisfaction according to types of buildings. For office buildings, air quality, temperature and lighting were the most frequently studied parameters followed by HVAC usability, and outside views through windows [6–9]. However, the empirical studies examined the impact of IEQ on user satisfaction, but not how building design factors affect user satisfaction with indoor environment. When the users are considered in the early design phase, the design approach may be different than in conventional design approaches that users are not considered.

Therefore, the primary purpose of this paper is to predict the effect of building design factors on environmental user satisfaction through the field study and provide insight by reporting on the satisfaction differences according to different design parameters in offices. This paper aims to answer the research question: Which office design factors contribute to thermal and visual satisfaction, and which are factors contribute to improve it? The scope of this study is limited to

* Corresponding author. Julianalaan 134, 2628 BL, Delft, the Netherlands
E-mail address: M.Kwon@tudelft.nl (M. Kwon).

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environmental satisfaction and a selection of architectural design parameters of the workplace. This selection is described followed by data collection and statistical analyses. Finally, predicted satisfaction models are suggested to improve environmental satisfaction in workspaces.

2. Literature review

2.1. Keywords selection

Prior to proceeding with the methodology, the main design factors affecting occupant satisfaction and energy performance of the office building are described in this section. The key search terms of the literature search were applied as follow: (office design elements or office design factors or office design) AND (energy efficiency) AND (user satisfaction or occupant satisfaction) AND NOT (school) AND NOT (house) AND NOT (hospital). 17 papers were selected based on the purpose of the paper, which is to predict the correlation of physical design factors for office buildings with the level of IEQ satisfaction.

2.2. Physical design factors influence on user satisfaction

Table 1 shows a summary of design parameters that have been investigated in other studies. Although there are many studies related to occupants' satisfaction with energy efficiency in office buildings, and the impact of façade components and office layout on IEQ, only a few studies deal with the relationship between user satisfaction or comfort and design parameters. The office design parameters can be divided into two categories with sub-parameters: spatial office design such as layout and position of work places, and façade design such as orientation, window-to-wall ratio (WWR). The effective façade design gives influence on IEQ and user satisfaction as well as orientations. Hua et al. [10] revealed that the level of occupant's satisfaction with IEQ was different according to orientations. However, office types such as individual office and shared office was not statistically significant.

2.2.1. Office layout

In early studies, office layouts were classified by different dimensions. Vos et al. [26], an idea of an office layout was classified by location, the internal configuration of space and the use of space. Dobbelsteen [27] defined workplace layout in terms of spatial concepts which have an influence on the interaction of people, the type of climate control, spatial flexibility and spatial efficiency. Danielsson and Bodin [11] defined office types by different architectural and functional features.

The cellular layout provides individual workspace along the façade accommodating 1–3 workplaces in one cell [26]. The single cell provides a work environment for high concentration and people can adjust their own preferred indoor climate. The open-plan office type emphasises flexibility of space, sharing workspace with more than 13 persons [26]. For this type, people complained about the quality of the indoor climate, for instance regarding unpleasantly high or low temperatures, lighting and noise levels etc. The combi-office is an office type that integrates the single-cell type and open-plan type, combined with more types of spaces [11,27]. This type is a group work-based plan, and adapted advantages of cellular and open-plan offices [27]. Employees can work independently, and at the same time, the office provides open space where people can relax and communicate. Flex-office means that no individual workstation includes backup spaces. It is dimensioned for < 70% of the workforce to be present simultaneously [11].

2.2.2. Desk location

Desk location here indicates work desk's distances from windows, having a direct effect on satisfaction with IEQ [1,28]. With the importance of this factor, Mofidi and Akbari [29] developed a position-based evaluation method for user comfort and energy management. Recent studies of Kong et al. [20] tested occupant's satisfaction with their visual comfort based on the distance from windows. They noted that a location 2.3 m from the windows can protect the building users from the direct sunlight. Awada and Srour [30] and Altomonte et al. [31] classified the parameter based on the location of desks within 4.6 m and further than 4.6 m from the nearest window. A study of Christoffersen and Johnsen [32] measured the satisfaction rate according to the position of desks in window, mid, and wall zones, with less than 7 m depth. They monitored light quality at 2 m from the window. By considering these early studies, desk location comprised three groups in this study: 0–2 m, 2–4 m and over 4 m.

2.2.3. Orientation

Seating orientations contribute to the visual comfort in offices

Table 1
A summary of influential design parameters for user satisfaction based on literature reviews.

Authors	Design factors	Findings
Danielsson and Bodin [11]	Office design	Individual's perception related to health and job satisfaction are different according to office types.
Seddigh et al. [12]		Office layout influences occupants' health and performance.
Zerella et al. [13]		Layout features are highly associated with employee perception of work satisfaction.
Lee [14]		Office layout affects worker perception regarding environmental quality issues (LEED-certified buildings)
Schiavon and Altomonte [15]		Open space layout in LEED buildings showed successful improvement of occupant satisfaction with IEQ, including office type, spatial layout, distance from window, occupants' demographics, occupancy hours.
Baird et al. [16]		Office layout is a major factor affecting overall occupant comfort.
Shahzad et al. [17]		Cellular office equipped with personal thermal control showed 35% higher satisfaction and 20% higher comfort level compared to open plan offices.
Rao [18]		Open space layout will cause reduction of acoustic quality.
Mofidi and Akbari [19]	Desk location, and dimension	Position-based comfort depends on the dimension of the office, orientation, desk location and placement of openings.
Kong et al. [20]	Environmental variations	Distance from windows, orientations and window heights significantly affect user satisfaction with daylight and visual comfort.
Aminu Dodo et al. [21]	Façade design and orientation	Orientation, and area of windows determine daylight quality and thermal condition.
Hua et al. [10]	Façade design	Glazing and shading designs need to be considered for thermal and daylight performance
Tzempelikos et al. [22]		The impact of WWR and glazing type on thermal comfort was studied for optimal choice of a façade.
Lee et al. [23]		The study tested building performance based on the relationship between WWR and orientation.
Jin and Overend [24]		The impact of façade-intrinsic and extrinsic design parameters (e.g., WWR, thermal properties, and orientation HVAC system) are evaluated in chamber-based research.
Hua et al. [10]	Orientation	Orientation is an important factor for thermal and visual comfort and energy efficiency of workspaces.
Konis [25]		Visual discomfort observed frequently in S.E perimeter zone due to direct sun-light.
Rao [18]		Building orientation may determine solar radiation.

Based on previous studies, design factors can be classified as four parameters: office layout, desk location, orientation, and WWR.

[25,33]. In the same way, Hua, et al. [10] stressed that orientation is highly correlated to the visual comfort, especially extreme illuminance was observed in both southwest and northeast orientation. The studies also reported that certain orientations caused high levels of thermal dissatisfaction. However, it is difficult to say that orientation was the main reason that causes occupant's discomfort since other factors such as glazing area, artificial lighting, and blinds may also affect occupants' visual comfort.

2.2.4. Window-to-wall ratio (WWR)

Many studies stated the importance of the glazing area for thermal comfort and daylight [10,21–23]. WWR has an impact on building performance in terms of indoor quality due to the influence on natural daylight, heat gain/loss and optical properties, and windows and outside views are psychologically important to employees [34,35]. The WWR is calculated by dividing the glazed/window areas by the gross exterior wall area for a particular facade. In other words, it is the ratio between the transparent area versus and the opaque area of the facade. Goia et al. [36] claimed that the range of 35–45% of WWR is the optimal rate in terms of energy minimisation. This result can be applied to Atlantic and Central Europe only. Further research of Goia [37] proposed WWR ranges and orientations for different climate conditions in Europe. Köppen Classification for The Netherlands is Cfb (Marine West Coast Climate). According to Goia [37], WWR for Cfb classification is 37–45% for south, 40–45% for north, 37–43% for west, and 37–43% for east orientation. Modern offices often have a fully glazed façade. In order to cover the various range of WWR of office buildings, the WWR was classified by three types: 30%, 50%, and 80%.

3. Methodology

3.1. Building selection

Five office buildings were chosen as case studies to investigate influential design factors for user satisfaction. The offices selected are cellular, open, combi and flex-offices, but the different floors are sometimes planned differently. Fig. 1 describes the case study buildings. The buildings were originally built in the 1960s–1980s and have been occupied at least one year after a renovation with energy rating A, based on energy performance certificate (EPC) in the Netherlands. The renovation strategies mainly focused on energy efficiency. Each case has comparable building orientations to that of the other buildings. In terms of building operations, all buildings have climate ceilings, which serves both heating and cooling for indoor climate. The buildings rely on artificial light and daylight with sun-shades.

3.2. Dataset

In this study, literature was reviewed to design questionnaires, and responses of the questionnaires were analysed by statistical analyses.

3.2.1. Questionnaires

Design parameters, as objective variables, were selected based on the literature review. The questionnaires included 4 main design factors, with independent variables such as distance from windows of desk location, orientation, office layout, and WWR and 8 dependent variables relating to occupant's satisfaction with the indoor environment. Four questions were given to responses to collect the information about individuals' work environments. Table A1 describes survey questions and possible answers. Additionally, a digital map link showing pin points of each office was included in the questionnaire to get correct responses regarding orientations. User satisfaction measurements, as subjective variables, consisted of parameters such as temperature, air quality, humidity, overall comfort, noise, light (artificial lighting), daylight, and view to the outside. Office occupants were asked "how satisfied are you with the following conditions?" These variables measure the degree of satisfaction using a five-points Likert scale ranging from 1 = extremely dissatisfied, 2 = dissatisfied, 3 = neither dissatisfied nor satisfied, 4 = satisfied, 5 = extremely satisfied. The scope of user satisfaction was limited to IEQ related parameters. The questionnaire involved eight IEQ themes (e.g., temperature, humidity, air quality, artificial lighting, daylight, outside view, noise, overall comfort). Occupants were supposed to answer their satisfaction level per theme for different seasons.

3.2.2. Responses

Occupants from the five case study offices located in the Netherlands were invited to take the web-based survey through an invitation e-mail including the survey link. In order to collect more responses, paper questionnaires were also distributed during working hours. Table 2 shows the participation rate used in the analysis. 718 occupants were approached, 139 (19.4%) counted as missing cases, and 579 (79.5%) completed the survey. For data cleaning, the missing cases were excluded in the statistical analysis.

The gender balance between male and female was almost 50%, and the age of 30–49 accounted for half of the total responses. The respondents' group was composed of 66.7% of full-time employees and 33.3% part-time (see Fig. 2).

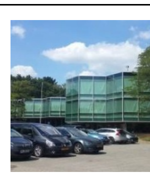
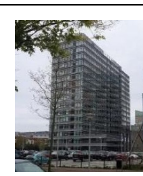
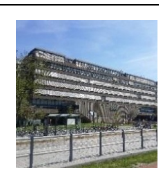
	Case A	Case B	Case C	Case D	Case E
Case					
WWR	≤ 30%	≤ 80%	≤ 50%	≤ 50%	≤ 30%
Location	Location: Den Haag, the Netherlands	Location: Amersfoort, the Netherlands	Location: Den Haag, the Netherlands	Location: Den Haag, the Netherlands	Location: Delft, the Netherlands
Built year	1973	1971	1975	1960s	1960
Adaptation	2010 – 2011	2012	2008	2012	
Energy label improvement	F to A (EPC)	G to A (EPC)	Energy label A, BREEAM Very good	BREEAM Excellent	No information

Fig. 1. Description of case study buildings.

Table 2
Number of participants in the questionnaire and completion rate.

Occupants responses	Case A	Case B	Case C	Case D	Case E	Total
Started survey	46	161	102	306	103	718
Completed survey	39	142	41	279	78	579
Percentage	84.8%	88.2%	40.2%	91.1%	75.7%	80.6%

3.3. Statistical data analysis

Data were analysed using SPSS 24. First, the number of dependent variables (satisfaction parameters) had to be reduced to fewer number of dimensions by grouping similar patterns of responses. The process can simplify the data and prevent multi-collinearity error. Factor analysis was conducted to establish the underlying data structure with Oblimin rotation (oblique solution), to find out if the factors were correlated [38]. Two factors (e.g., thermal-related satisfaction and visual-related satisfaction) were identified to explain over 70% of the variance in the data structure by the factors that were extracted.

Next, aggregate variables were created based on the factor analysis and henceforth these were recoded into binominal variables to create a redundant and more powerful model. However, the collected dataset showed non-normal distributions. Dependent variables were ordinal, and independent variables were nominal variables, which made it difficult to interpret the relevant comparisons. Categorical regression (CATREG) [39], also called regression with optimal scaling [40], circumvents this problem by converting nominal and ordinal variables into interval scales [41], and also circumvents the issue of unequal sample sizes between the cases since the analysis uses a weighted average according to Ref. [42].

Last, binary logistic regression was used to find out which independent variables are predictive for satisfaction with thermal comfort and visual cognitive satisfaction. This analysis is a direct probability model and was used to investigate whether or not an occupant was satisfied with the workplace environment. Moreover, the results of the logistic regression also showed in which design users were most satisfied. To perform the binary logistic regression, a 5-point Likert response scale from 'extremely dissatisfied' to 'extremely satisfied' was recoded to be 'dissatisfied = 0' and 'satisfied = 1' denoting the agreement of satisfaction parameters. Desk location, orientation, layout and WWR were entered as explanatory (categorical) variables. The last dummy was the reference category as each category compared against each other. In order to check whether or not the model is fit to the data, the Hosmer-Lemeshow (Chi-square) [43] test was conducted. The H0 hypothesis is that the model is a good enough fit with the data ($p < 0.05$) that allows to estimate values of the outcome variables [44]. H1 is that the model is not a good enough fit to the data. Next, the confidence interval (CI) was checked with 95% confidence level.

Table 3
Results of factor analysis based on structure matrix with Oblimin rotation.

	Loadings			
	Factor 1: Thermal comfort-related satisfaction	Factor 2: Visual comfort-related satisfaction	Communalities	Cumulative (%)
Temperature	**0.880**		0.634	56.979
Air quality	**0.874**		0.599	
Humidity	**0.855**		0.722	
Overall comfort	**0.793**		0.775	
View to outside		**0.850**	0.738	71.397
Daylight		**0.835**	0.731	
Artificial lighting		**0.700**	0.797	
Noise		Eliminated		

4. Results

4.1. Data extraction of user satisfaction variables

The first step in the analysis was to check how the indoor satisfaction variables clustered together and to learn about the underlying structure. Indoor satisfaction variables were analysed with Oblimin rotation of factor analysis. When p-value ≤ 0.05, the test results were considered as statistically significant. Two factors were established: thermal and visual comfort (see Table 3). The first factor consists of items describing thermal affective dimensions such as temperature, air quality, humidity and overall comfort. Factor 1 was labelled thermal comfort-related satisfaction. The first factor explained 57.0% of variance. The second factor was labelled visual comfort-related satisfaction that consists of view to outside, daylight, and artificial lighting. Together these factors explained over 71.4% of variance. A KMO (Kaiser-Meyer-Olkin measure) and Bartlett's test were conducted to check if these factors met sample adequacy. 0.865 of KMO value exceeded the accepted value of 0.5, and Bartlett's test of Sphericity was significant ($X^2(21) = 2128.70$, $p < 0.001$. This indicates that the samples' adequacy can be accepted and validated the significance of this study. Noise was eliminated from satisfaction factors due to low factor loading (under 0.5), and it represented a different construct. Substantively, two tendencies were identified which are independent of one another.

4.2. Exploring design factors related to user satisfaction

The categorical regression analysis was performed using the enter

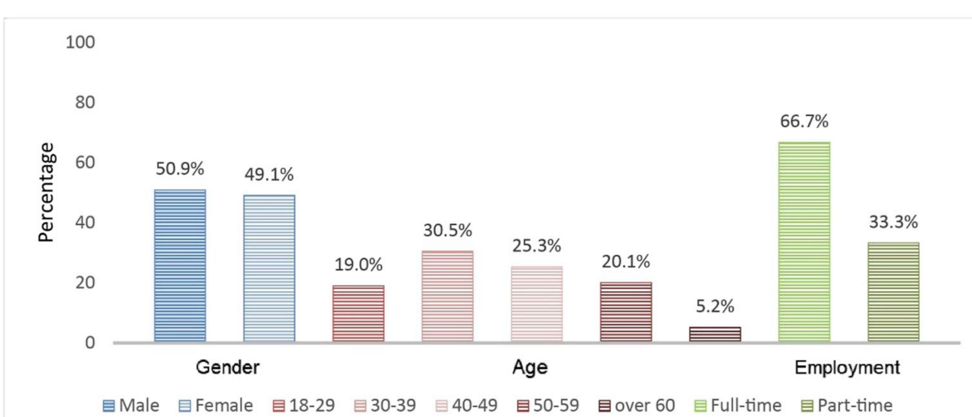


Fig. 2. Demographic information of respondents.

Table 4
Results of categorical regression analysis (N = 579).

	Dependent	Independent	β	Importance	*P*-value	R^2	*P*-value
Mid-season	Thermal satisfaction	Desk location	**0.269**	**0.586**	$p < 0.001$	0.128	$p < 0.001$
		Orientation	0.106	0.131	$p < 0.001$		
		Layout	0.185	0.263	$p < 0.001$		
		WWR	0.046	0.020	0.184		
	Visual satisfaction	Desk location	**0.180**	**0.408**	$p < 0.001$	0.088	$p < 0.001$
		Orientation	0.125	0.214	$p < 0.001$		
		Layout	0.168	0.309	$p < 0.001$		
		WWR	0.069	0.068	0.026		
Summer	Thermal satisfaction	Desk location	**0.230**	**0.406**	$p < 0.001$	0.149	$p < 0.001$
		Orientation	0.191	0.306	$p < 0.001$		
		Layout	0.183	0.218	$p < 0.001$		
		WWR	0.094	0.069	0.007		
	Visual satisfaction	Desk location	**0.189**	**0.420**	$p < 0.001$	0.093	$p < 0.001$
		Orientation	0.141	0.238	$p < 0.001$		
		Layout	0.162	0.304	$p < 0.001$		
		WWR	0.058	0.038	0.086		
Winter	Thermal satisfaction	Desk location	0.212	**0.386**	$p < 0.001$	0.124	$p < 0.001$
		Orientation	0.126	0.184	$p < 0.001$		
		Layout	**0.213**	0.332	$p < 0.001$		
		WWR	0.110	0.097	0.001		
	Visual satisfaction	Desk location	**0.206**	**0.511**	$p < 0.001$	0.092	$p < 0.001$
		Orientation	0.094	0.126	0.002		
		Layout	0.167	0.305	$p < 0.001$		
		WWR	0.058	0.059	0.071		

Note: p-values in bold highlighted are statistically significant ($p < 0.05$).
β coefficients in bold highlighted mean the largest satisfaction coefficient.

method, to identify the relative contribution of influential design factors on user satisfaction and to predict the factors in all seasons. The enter method prevents the elimination of the variables that are significant but have a weak contribution. These regression models, based on two factor models, were designed for each season. The results describe which design parameters had substantial contribution to user satisfaction with thermal and visual comfort, and how user satisfaction depends on desk location, orientation, layout and WWR.

Table 4 shows the relative contribution of influential design factors on user satisfaction. R^2 indicates how well the model fits the data.

$$R^2 = \frac{\text{Variance explained by the model}}{\text{Total variance}}$$

The range of R^2 was between 9.0% and 15.0%, which were relatively low R-squared values. However, the regression models showed that independent variables were statistically significant. Therefore, objective variables (desk location, orientation, layout, and WWR) were found to be significant predictors for user satisfaction in the work environments. All objective variables had a positive relationship with satisfaction parameters. β value refers to the standardised coefficient. In detail, the largest coefficient of thermal satisfaction occurred in ‘desk location’, $\beta = 0.269$, $p < 0.001$, for mid-season, $\beta = 0.230$, $p < 0.001$ for summer, and $\beta = 0.212$, $p < 0.001$ for winter. The largest coefficient of visual satisfaction occurred in ‘desk location’, $\beta = 0.180$, $p < 0.001$ for mid-season, $\beta = 0.189$, $p < 0.001$ for summer, and $\beta = 0.206$, $p < 0.001$ for winter, followed by ‘layout’.

To interpret the contributions of four predictors, it is important to inspect Pratt's measure of relative importance. The largest importance corresponded to ‘desk location’, ‘layout’, and ‘orientation’ accounting for over 90% of the importance. Despite of the relatively small standardised coefficient of ‘orientation’, the large importance of 0.306 occurred in the satisfaction with thermal comfort in summer. In summary, ‘desk location’, ‘layout’, and ‘orientation’ predictors highly contributed to environmental user satisfaction in workplaces.

Fig. 3 illustrates which of the independent design variables have a greater impact on user satisfaction with thermal and visual comfort in different seasons. Taken together, ‘desk location’ and ‘layout’ showed greater impact on thermal and visual comfort regardless of seasons. On the other hand, ‘WWR’ was the least important predictor for satisfaction with thermal comfort, and the variable did not significantly attribute to visual comfort in summer and winter but mid-season. Although ‘orientation’ was a significant predictor, the beta weight was relatively smaller than that of ‘desk location’ and ‘layout’.

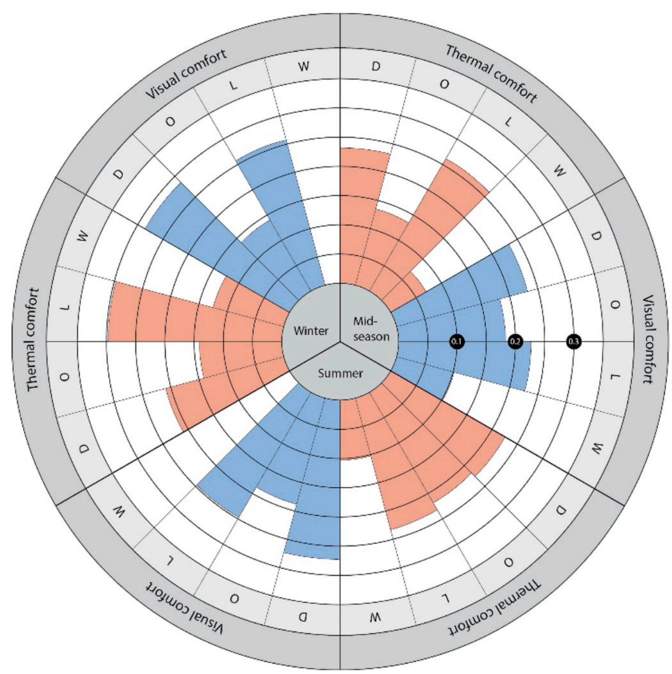


Fig. 3. Influential weight of design parameters on user satisfaction with thermal and visual comfort.

Fig. 4 displays nominal transformation plots for design parameters. It shows the relationship between the quantifications and the independent categories selected by optimal scaling level. It was created based on categorical regression. It shows the tendency of user satisfaction for design factors. The X axis represents the order of the codes used in each parameter, and the Y axis represents the quantification

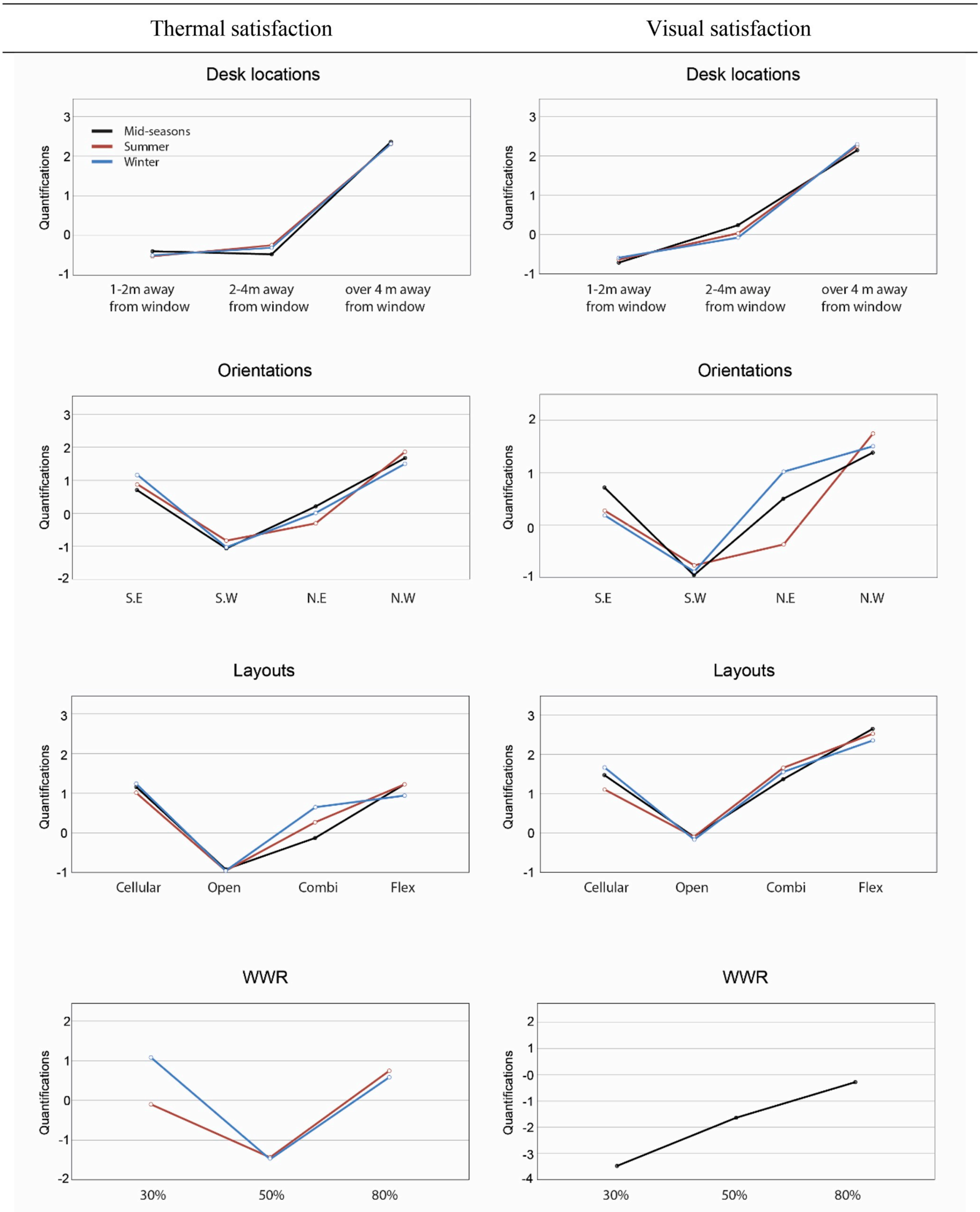


Fig. 4. The relationship between physical design factors and user satisfaction based on categorical regression.

values of transformed dependent variables. The original values of dependent variables are categorical; therefore, the values were transformed to numerical quantification through the optimal scaling. The procedure of transformation allows categorical variables to be analysed to find the best-fitting model [45]. The transformed quantifications are the values assigned to each category to make non-linear relation and reflects characteristics of the original categories [46]. Therefore, each quantification value itself is not important. For example, 'over 4 m distance from windows' showed the largest quantification, therefore, increasing the predicted satisfaction level. First, for the desk location placed far away from windows, people were more satisfied with the thermal and visual satisfaction. Second, cellular office as one of four layouts showed the highest satisfaction for thermal comfort in mid-season and winter among four layouts. In summer, however, the flexible office showed a higher thermal satisfaction than the cellular type. On the other hand, open-plan office was the worst layout for thermal comfort for all seasons. For visual satisfaction, the pattern was quite similar, but combi and flexible offices tended to be preferred and resulted in higher visual satisfaction. Next, the orientation that the occupants were most satisfied with was north-west, and least satisfied was south-west for both thermal and visual satisfaction. The results of thermal satisfaction in mid-season, and visual satisfaction with comfort in summer and winter according to WWR were not statistically significant. Therefore, the graphs were eliminated.

4.3. Predicted environmental user satisfaction

Based on a categorical regression test, variables of 'desk location', 'layout', and 'orientation' were further examined by the binary logistic regression using office design factors as the dependent variable and thermal and visual satisfaction as the independent variable. Nagelkerke R^2 [47] shows that the model explains roughly 20–25% of the variation in the outcome. Hosmer-Lemeshow test indicates goodness of fit for logistic regression. The *p*-value was higher than 0.05 so that the model fits the data.

Table 5 shows the results of the logistic regression reporting a regression coefficient (B), an odds ratio (β), and *p*-value. In the model, one less than the number of categories were created as dummy variables. Therefore, desk location over 4 m away from window, N.W, and flex-office layout were omitted, and calculated as the base variables. The results represent that there was a statistical significance between desk location and environmental satisfaction. In detail, occupants who sit over 4 m away from the windows were 3.85–5.71 times more satisfied with the thermal comfort than those who sit closer to the windows, and 2.65–7.25 times more satisfied with the visual comfort. The impact of orientation on satisfaction was only significant for thermal satisfaction in summer, and visual satisfaction in mid-season and summer. South-west and north-west façade had strong impact on thermal and visual comfort, mainly in summer. Occupants of workplaces facing to the north-west orientation were 3.53–4.50 times more satisfied (followed by those who sit on the north-east) than were people facing south-west. As the results of categorical regression analysis shows, office layout was an important predictor for environmental satisfaction for all seasons. The prediction impact between open plan and flex-office was significant, $p < 0.05$. The occupants in flex-office tended to be 3.55–4.07, and 3.90–4.85 times more satisfied with thermal and visual comfort respectively than those in open-plan offices.

5. Discussion

5.1. Design factors as predictors of occupant satisfaction

This study attempted to identify which design factors among desk location, layout, orientation, and WWR play a major role for the occupants' satisfaction with thermal and visual comfort. As shown in Tables 3 and 4, the occupants' satisfaction with thermal and visual comfort were statistically different according to the 'desk location', 'office layout', and 'orientation'. In contrast, WWR was not a

Table 5
Results of binary logistic regression of design factors and IEQ user satisfaction: Hosmer-Lemeshow test, Odd-ratios are reported with confidence intervals parentheses and *P*-value (N = 579).

Variable	Mid-season			Summer			Winter		
	B	Exp (β)	*P*- value	B	Exp (β)	*P*- value	B	Exp (β)	*P*- value
Desk location			***p* < 0.001**			***p* < 0.001**			**0.001**
0–2 m	**−1.631**	**0.196**	***p* < 0.001**	**−1.746**	**0.175**	***p* < 0.001**	**−1.485**	**0.226**	***p* < 0.001**
2–4 m	**−1.531**	**0.216**	***p* < 0.001**	**−1.601**	**0.202**	***p* < 0.001**	**−1.347**	**0.260**	**0.002**
Orientation			0.069			***p* < 0.001**			0.070
S.E	−0.460	0.631	0.343	−0.636	0.529	0.191	−0.375	0.687	0.433
S.W	−0.975	0.377	0.011	**−1.503**	**0.222**	***p* < 0.001**	−0.962	0.382	0.012
N.E	−0.693	0.500	0.080	**−1.321**	**0.267**	**0.001**	−0.660	0.517	0.099
Layout			**0.000**			***p* < 0.001**			***p* < 0.001**
Cellular	0.090	1.094	0.836	−0.239	0.787	0.552	0.134	1.143	0.760
Open	**−1.267**	**0.282**	***p* < 0.001**	**−1.283**	**0.277**	***p* < 0.001**	**−1.402**	**0.246**	***p* < 0.001**
Combi	−0.816	0.442	0.077	−0.602	0.547	0.202	−0.454	0.635	0.338
Thermal satisfaction	Omnibus test *P*- value	Nagelkerke R^2	Hosmer-Lemeshow test	Omnibus test *P*- value	Nagelkerke R^2	Hosmer-Lemeshow test	Omnibus test *P*- value	Nagelkerke R^2	Hosmer-Lemeshow test
	p < 0.001	0.210	0.535	*p* < 0.001	0.255	0.700	*p* < 0.001	0.224	0.423
Desk location			**0.002**			***p* < 0.001**			***p* < 0.001**
0–2 m	**−1.661**	**0.190**	**0.001**	**−1.953**	**0.142**	***p* < 0.001**	**−1.981**	**0.138**	***p* < 0.001**
2–4 m	**−0.972**	**0.378**	**0.045**	**−1.216**	**0.296**	**0.015**	**−1.626**	**0.197**	**0.001**
Orientation			**0.038**			**0.034**			0.165
S.E	−0.801	0.449	0.141	−0.555	0.574	0.304	−0.591	0.554	0.292
S.W	**−1.285**	**0.277**	**0.005**	**−1.262**	**0.283**	**0.007**	−1.063	0.345	0.031
N.E	−0.647	0.524	0.170	−0.434	0.648	0.370	−0.498	0.608	0.322
Layout			**0.005**			**0.002**			**0.002**
Cellular	−0.533	0.587	0.300	**−1.090**	**0.336**	**0.042**	−0.978	0.376	0.069
Open	**−1.363**	**0.256**	**0.001**	**−1.578**	**0.206**	***p* < 0.001**	**−1.487**	**0.226**	***p* < 0.001**
Combi	−0.626	0.534	0.245	−1.037	0.355	0.064	−0.364	0.695	0.526
Visual satisfaction	Omnibus test *P*- value	Nagelkerke R^2	Hosmer-Lemeshow test	Omnibus test *P*- value	Nagelkerke R^2	Hosmer-Lemeshow test	Omnibus test *P*- value	Nagelkerke R^2	Hosmer-Lemeshow test
	p < 0.001	0.229	0.743	*p* < 0.001	0.248	0.515	*p* < 0.001	0.245	0.917

Note: B coefficients and odd ratio (β) in bold highlighted are statistically significant ($p < 0.05$).

statistically significant factor for thermal and visual satisfaction. The results from 579 office occupants showed that 'desk location' was the most influential factor to optimise IEQ satisfaction.

5.1.1. Desk location

Awada and Srour [30] reported that employees who are close to a window tend to be more satisfied with IEQ conditions than those who are far away from a window. In contrast to their study, the results of this study showed that occupants who sit far away from windows tend to be more satisfied with environmental comfort compared to occupants who sit close to windows. Interestingly, there was no difference on the responses of satisfaction with thermal and visual comfort in different seasons. According to descriptive analysis, around 37% responded neither dissatisfied nor satisfied with thermal satisfaction, and over 60% for visual satisfaction in different seasons, followed by dissatisfied. In other words, people were almost equally responded their satisfaction in questionnaires. The study in this paper showed that workstations located close to windows have a bigger chance to be exposed to overheating indoor spaces due to the direct sun [48] and unwanted illumination [49]. Kamaruzzaman et al. [50] also revealed that thermal and glare level can be problems according to how close people sit from the window.

5.1.2. Orientation

Despite of the importance of design factors, few studies included 'orientation' as a design factor or a building feature in thermal comfort studies, since some studies stated that 'orientation' is not correlated to thermal comfort [10,51]. On the other hand, Sadeghi, et al. [52] emphasised considering the influence of different façade orientations on visual preference. Our study included 'orientation' as one of the design factors, and proved that the factor was comparatively less relevant to the satisfaction. However, the result in this paper, showed that it was a considerably important factor for the satisfaction with thermal comfort in summer. Similarly, Konis [25] revealed that 'orientation' has an impact on visual comfort, and people on the N.W zone were dissatisfied due to the direct sun and glare. Hua et al. [10] revealed that satisfaction with temperature is low regardless of orientations in both summer and winter. It means that orientation has no influence on the satisfaction with temperature. Instead, orientation contributed to the level of visual comfort with glazed façades. It is assumed that the existence of façade elements such as window blinds and management of the system could cause the different results.

5.1.3. Office layout

The findings in this study consisted with earlier study by Bluyssen et al. [53], addressing that office layout has a primary impact on the comfort satisfaction in summer and winter. A study by Altomonte et al. [31] revealed a strong correlation between spatial layout and workplace satisfaction and addressed that spatial design factors have a substantial impact on user satisfaction. The results related layout are in line with the findings of Altomonte et al. [54] and Shahzad et al. [55], which revealed that IEQ satisfaction and thermal comfort are higher in cellular offices than open offices. It assumed that people have the high availability of thermal and lighting control in cellular offices than open offices.

5.2. Statistical analysis

Evaluating users' comfort and satisfaction is complicated since it is difficult to interpret the results and to find a representative time and sample [56]. Some studies used various statistical analysis to investigate the relationship between building characteristics and occupants' comfort or satisfaction. Factor analysis is often implemented for user studies to investigate variable relationships [57,58]. In such a way, the analysis can reduce multi-collinearities and can group variables into statistically correlated groups [2,59]. By performing the factor analysis, two underlying factors (thermal comfort and visual comfort) were proposed, which had bigger impact and could better explain occupants' responses towards environmental satisfaction. Similarly, a literature review defined occupants' comfort by four categories: thermal, visual, acoustic and indoor air quality [60].

Later, we performed categorical and binary logistic regressions [61]. Frontczak et al. [1] addressed that logistic regression can help to find the relative importance among IEQ parameters and building characteristics. Wong et al. [62] examined IEQ parameters based on thermal comfort, air quality, acoustic comfort and illumination through a logistic regression model. However, the analysis can be used to predict the influence of design factors on user satisfaction. In this study, the CATREG was used before the logistic regression since the analysis can be implemented for a non-linear transformation of multiple (non-binary) dependent and independent variables to determine the logistic factors affecting dependent variables [63]. The analysis uses optimal scaling method to assign numerical quantification to the categories of each variable [46]. It contributes to narrowing the focus variables. Consequently, binary logistic regression used to verify the significance of each predictor with dummy variables and to prevent a multi-collinearity problem in the linear multiple regression model. Therefore, this statistical approach may provide an appropriate process for user-based studies in the indoor environment and draw general conclusions in the different work environment.

5.3. Limitations

The analysis compares one design parameter to each satisfaction variable. In reality, indoor climate is influenced by a combination of design factors, not one by one. Although certain design options showed a better outcome, it is necessary to consider the combination of a design option with other design options. Therefore, a limitation of this study is that it is difficult to say that the suggested design options will always lead to the best results in terms of occupants' satisfaction. Second, noise was excluded by factor analysis. Thus, noise needs to be studied separately from IEQ study. Last, the results to buildings located in other climates may lead to different conclusions. However, the study's approach can be used for different scenarios dealing with user studies. The findings may contribute to a user-focused office design during the conceptual design phases.

6. Conclusion

Office buildings have been mainly designed based on practical aspects following design guides. Design factors have not been tested by occupants' satisfaction. This paper demonstrates influential design factors that can satisfy occupants' thermal and visual comfort by focusing on architectural space and façade design, and they were evaluated by the user-focused subjective assessment in real office spaces. The subjective assessment by users was a useful method to evaluate design factors and its impact on the working environment.

The findings provide an insight into the relationship between design factors and user satisfaction in workplaces, and the attributes of design factors on thermal and visual satisfaction. This can help to understand the gap between design intension and occupant's satisfaction. The results also suggest a relative significance of design parameters, and show which alternative option is more attractive for office users. The planners and architects can consider the following suggestions:

- For the user satisfaction-related study, IEQ categories (e.g., temperature, humidity, air quality, lighting, daylight, view to outside, overall comfort) can be classified by thermal and visual comfort. However, acoustic comfort needs to be analysed separately from the IEQ satisfaction model, as acoustic comfort clearly did not load on any of the factors identified in the factor analysis.
- Office layout and desk location as the factors contributing most

strongly to user satisfaction should be considered during the office design process.

- Despite the weak relevance of 'orientation' for thermal and visual comfort, 'orientation' can be a significant factor for thermal comfort in summer. Moreover, workspaces facing north-west and north-east are recommended to provide higher satisfaction with thermal comfort than other orientations. It is assumed that north-oriented workspace can avoid overheating during summer.
- With similar reasons, having distance from window for working desks can increase the level of satisfaction by preventing a sudden temperature difference and unwanted illuminance.
- In contrast, WWR may not affect occupants' satisfaction with thermal and visual comfort. However, it was one of the important factors having impact on energy savings.
- The same methodology can be applied to the user-related research. However, more complex models in which different design parameters interact need to be explored for further research. Moreover, the results of predicted models can be tested in different climate zones.

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Appendix A

Table A.1
Questions about physical condition of workplaces

Categories	Question	Answer
Desk location	Where is your desk located?	1 = 0–2 m away from windows, 2 = 2–4 m away from windows, 3 = Over 4 m away from window
Orientation	Which direction does your window face?	1 = South-east, 2 = South-west, 3 = North-east, 4 = North-west
WWR	What types of windows does your workplace have? (Choose what comes closest to your situation)	1 = 30%, 2 = 50%, 3 = 80%
Office layout	What type of office layout do you work at?	1 = Cellular, 2 = Open plan, 3 = Combi-office, 4 = Flexible office
Satisfaction	How satisfied are you with the following conditions? (Temperature, air quality, humidity, view to outside, lighting, daylight, noise, overall comfort)	1 = Extremely dissatisfied, 2 = Dissatisfied, 3 = neither dissatisfied nor satisfied, 4 = Satisfied, 5 = Extremely satisfied

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