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Does the Number of Occupants in an Office Influence Individual Perceptions of Comfort and Productivity?—New Evidence from 5000 Office Workers

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Abstract: Purpose—The purpose of this article is to present evidence of occupants' perception of their work environment in five different office types (Solo, Duo, 2–4, 5–8 and 8Plus offices). The study examined the influence of the number of office occupants on individual perception of indoor environment quality (IEQ) in office environments. Design/methodology/approach—A dataset of 5000 respondents in 67 commercial and institutional office buildings was analysed using IBM SPSS v23. The dataset contained user response on the BUS Methodology questionnaire that is designed to retrieve occupants' perception of their work environments. Analysis of Variance (ANOVA) and multiple regression analysis were conducted to calculate the impact of the office environment on occupants' perception of comfort and productivity. Findings - This study showed that occupants in Solo and Duo offices perceived higher satisfaction with their environment (except for temperature in summer), better health and productivity; and more control over the office environment than those in 5–8 and 8Plus offices. Occupants in 8Plus offices were most satisfied with the temperature in summer. It was also noted that the IEQ factors that predicted comfort were observed to not predict productivity. Noise was the only IEQ factor that had predictive power for both comfort and productivity in all the office spaces. Originality/value—This article provides intriguing findings on occupants' perception of various types of office environment that contributes significantly to the debate on open-plan versus cellular office environments.

Keywords: perceived comfort; ieq variables; office environments; perceived productivity; personal control

1. Introduction

There is ongoing debate on the type of office environment that is not only comfortable for occupants but supports and enhances productivity [1–3]. At the centre of the debate is the comfort of occupants in office environments [4]. The comfort of an occupant in an office environment typically denotes the ability of the environment to provide pleasant and stimulating physical working conditions for occupants to be productive. The productivity of a worker is not only a matter of improving the speed and accuracy of routine tasks, but also generating new ideas, being creative, working effectively in teams, and creating knowledge that adds value to the organisation [4].

While organisations seek to increase collaboration by removing the spatial boundaries between occupants and create open, free flowing spaces, the question remains whether these spaces work.

Results of past studies both support [5,6] as well as refute [7,8] the concept of open-plan offices as enablers for communication, collaboration and even productivity in organisations. As the debate persists, the common limitation of past studies is the small sample size [1,9,10] that is characterised by the uniqueness of work carried out in the organisations and nature of workers. As such, there is a need for generalisable findings that represent the larger population of office workers. This study fills in the gap with a study carried out on a dataset of 5000 respondents in commercial and institutional office buildings on their perception of comfort and productivity in their office environments.

This study provides evidence of how occupants in five different types of office space perceive their work environments and how their perception impacts on reported comfort and productivity.

2. Background

The workplace environment has been shown to significantly impact employee health, comfort, productivity and engagement, in both positive and negative ways [11,12]. With the evolution of working styles and innovative communication methods, alternative workplace environments are needed to accommodate these rapid changes and support future office concepts. Reflecting the above, the physical environment of offices has evolved over the past decades, with open-plan offices, in contrast to traditional cellular offices, becoming a popular office design particularly for organisations wishing to reduce fixed overheads and increase employee density [13,14]. Traditional cellular or enclosed offices, tend to accommodate one or two individuals in private rooms, whereas open-plan offices are characterised by a lack of interior walls and tend to contain a greater number of individuals at separate workstations [13].

Cellular offices increase privacy, reduce unwanted interruptions, and may outperform open-plan layouts in terms of indoor environmental quality (IEQ) parameters [5,15]. Nevertheless, open-plan offices are easier to reconfigure, and accommodate changes in population density [16], while being aesthetically more pleasing. Open-plan offices also offer ease of collaboration and communication among colleagues compared to private offices [6]. Some studies reported increased employee satisfaction in open-plan offices regarding the social benefits obtained by working in an environment of mutual support and cooperation. Employees may favour open-plan offices because all staff including managing directors and new employees work in a single office environment [5]. Eliminating walls and creating open-plan offices creates a permeable set of boundaries between individuals and collaborating groups that can enable faster and easier communication [16].

Any reduction of occupant control over the working and living environment has historically been accompanied by reduced satisfaction and productivity [17]. Evidence has been found of dissatisfaction regarding open-plan layouts particularly in regards to noise and unwanted interruptions [18]. Open-plan offices with high noise levels may influence employee cognitive performance by reducing concentration, motivation and memory performance [19,20]. The degree of control over indoor climate, visual and auditory privacy, security and space for filing are other associated issues discussed in the literature [21–23].

One study showed that office type could have a greater influence on women rather than men due to different sensitivities to environmental stimuli and noise disturbances [24]. In a simulated experiment with 40 female employees, elevated urinary epinephrine levels, and motivational deficits in a low-intensity open-plan office environment were observed [25]. Job satisfaction was also correlated with work-years with the highest level of job satisfaction experienced by employees working in the company less than a year [26].

Satisfaction and dissatisfaction with open-plan layouts have different causes when comparing employers and employees in an office environment. Employers may favour open-plan because of lower construction costs, easier workforce management and increasing population density, and the flexibility of reconfiguration. Employees may prefer open-plan due to the ease of communication and exchange of information among colleagues in an office environment [5]. Open-plan layout developments clearly

challenge the tradition of cellular offices with higher occupant controls and privacy contributing to and sustaining professional identities [21,27].

A poorly designed office environment that fails to meet the requirements of a healthy and comfortable workplace impacts the employee's level of engagement with the organisation, error rates, the level of innovation and collaboration with other employees, absenteeism, and the length of stay in a job [11]. Workplace environments should be responsive to the dynamic functional, psychological, and physiological needs of the user [28]. Accordingly, many organisations are interested in investigating employee satisfaction with the workplace environment and open-plan configurations.

Reflecting the above, research has often reported lower satisfaction in open-plan offices regarding noise and unwanted interruptions, privacy, security, storage, and control over IEQ, all of which negatively impact concentration and productivity. However, open-plan offices may outperform cellular office layouts regarding factors such as collaborations, aesthetics; ease of reconfiguration and increasing density. Nevertheless, due to the difference in the nature of the work in academia in comparison with commercial offices, the increasing promotion of open-plan in both higher education and commercial organisations, should therefore be of critical interest to researchers. Previous studies have shown that different types of workspaces are required when comparing academics to commercial workers [29]. While open-plan office layouts with increasing path overlap seem to increase collaboration [30], concentration may improve in cellular offices due to enhanced privacy and less interruptions.

As indicated by the literature review above, there is still a gap in the debate on what type of spatial environment is best for workers in office environments. This research aims to examine the influence the number of office occupants has on their perception of comfort and productivity.

To achieve this aim, we set out the following objectives:

1. To examine the influence of number of office occupants on individual's perception of their office environment
2. To compare the perception of occupants on their health, overall comfort and productivity
3. To determine the extent to which the number of office occupants predicts comfort and productivity of occupants

3. Methodology

3.1. Data Collection and Analysis

To achieve the objectives set above, we used a dataset of about 5,000 responses from occupants in offices in 67 institutional and commercial buildings around the world on their perception of their workspaces. This dataset contains occupants' responses to post-occupancy evaluations carried out on their buildings using the standardised BUS Methodology questionnaire. The data is a collection of over 12 years of study on occupants' perception of their office environments across various countries. Developed for office buildings, the BUS questionnaire is popular for its robustness in representing occupants' perception of the performance of their work environment. This questionnaire has been applied internationally [31] and its results have been applied extensively to this field of research [32]. It contains 48 questions that target specific aspects of the buildings environmental features on a 7-point Likert scale of occupants' perception. The top three points (5–7) on the Likert scale denote satisfaction while the bottom three points (1–3) represent dissatisfaction with the variable tested. The procedures for data collection were in accordance with those outlined in the BUS Methodology (More information on the procedure for POE investigation using this questionnaire can be found at: https://www.busmethodology.org.uk/).

As this study was focused on the variables that concern the type of office environment occupants work in, this study addressed the following sections of the BUS questionnaire:

- Objective 1:
    - Perception of the office IEQ (Temperature, Air quality, Lighting and Noise) and
    - Perception of their work area (Furniture and Space at desk)
    - Perception of personal control over IEQ (heating, cooling, ventilation, lighting and noise)
- Objective 2:
    - Perception of health, overall comfort and productivity and
    - Change in occupants behaviour as a result of the office environment
- Objective 3:
    - Perception of office IEQ
    - Perception of personal control over IEQ
    - Perception of health, overall comfort and productivity

The data was analysed using the IBM SPSS vs 23 software. For ease of communication, the different office layouts tested in the BUS questionnaire were coded as follows:

1. Alone—"Solo offices"
2. Shared with 1—"Duo offices"
3. Shared with 2—4 persons—"2–4 offices"
4. Shared with 5—8 persons—"5–8 offices"
5. Shared with more than 8—"8Plus offices"

For Objective 1, descriptive analysis was carried out on occupants' perception of their office environment. The mean score rating between occupants of the five different layouts (Private office, shared office with one person, shared office with 2–4 persons, shared office with 5–8 persons and shared office with more than 8 persons) were compared to illustrate the correlation between occupants' perception of their office environment and the number of occupants they share with.

To ascertain whether there was a significant difference in perception between the number of occupants in an office on satisfaction with the office environment (Objective 2), an analysis of variance (ANOVA) between occupants' perception was conducted at 95% confidence interval ($p < 0.005$) for the means scores [33]. A Post hoc comparison using the Tukey HSD test was run to identify the variables whose mean rating scores were significantly different from each other. This exploratory statistical tool is used to explain observations within groups of data such as the one in this study.

Regarding Objective 3, multiple regression models were utilised to examine the effect of the number of occupants on perceived comfort and productivity [34]. A regression analysis identifies the significance of the impact of IEQ variables on occupants' comfort and productivity in the different office layouts examined.

3.2. Sample Characteristics

The analysis was carried on a database of 5000 occupants of 67 commercial and institutional office buildings around the world. Table 1 shows the characteristics of the building occupants surveyed. As shown in Table 1, the highest number of responses were from 8Plus offices (37%), followed by those in Solo offices (22.6%). The least number of responses was from people in Duo offices (8%). Most of all the groups of occupants had worked in their office spaces for over a year and spent 5 days or more, a week there. While most of the occupants in 2–4 offices and 5–8 offices have worked in their buildings for less than a year, the rest of the occupants have worked for more than a year in their office buildings.

Table 1. Occupants' characteristics.

Work Space Analysed	Response	Age	Gender	Worked in the Building	Worked in the Work Area	Hours Spent in Workspace in a Day
Solo Office	22.6%	85% (30 or over)	54% (female)	77% (more than a year)	65% (more than a year)	75.5% (8 hours or more)
Duo Office	8.1%	76% (30 or over)	55% (female)	66% (more than a year)	54% (more than a year)	69.2% (8 hours or more)
2–4 Office	17%	67% (30 or over)	51% (female)	65% (more than a year)	48% (more than a year)	70% (8 hours or more)
5–8 Office	15.1%	68% (30 or over)	53% (Male)	62% (more than a year)	48% (more than a year)	75.6% (8 hours or more)
8Plus office	37.1%	72% (30 or over)	51% (male)	69% (more than a year)	52% (more than a year)	80.1% (8 hours or more)
Country	New Zealand (56%), USA (2%), England (11%), Australia (17%), Canada (4%), others (10%)					

The proportion of male participants were only slightly higher in 5–8 offices and 8Plus offices with 53% and 51% distribution, respectively. The number of female participants from Solo, Duo and 2–4 offices were slightly higher with distribution of 54%, 55%, and 51%, respectively. The majority of the occupants in all office types were 30 years old and above. Therefore, it could be stated that the slight differences in the sample may be ignored and the dataset represents a consistent sample both in terms of gender distribution and age.

4. Findings

4.1. Objective 1: Occupant Satisfaction with Office Environment

Perception of Office IEQ

The occupants were asked to rate the typical working conditions in their work area in winter and summer seasons for temperature and air quality (1 = Uncomfortable; 7 = Comfortable), noise and lighting (1= Unsatisfactory; 7 = Satisfactory). Also, they were asked to rate the level of control they felt they had over the IEQ in their offices (1 = No Control; 7 = Full Control).

(a) Temperature in summer and winter

The mean rating and standard deviation results are depicted in Table 2 below. Generally, occupants in Duo offices were most comfortable with the overall temperature in winter (m = 4.69) while occupants in 5–8 offices were least comfortable (m = 4.50). In summer, occupants in 8Plus offices were most comfortable with the temperature (m = 4.47) whereas occupants in Duo offices were least comfortable (m = 4.32). Statistically, no significant difference in opinion was observed amongst the occupants' perception of the overall temperature in winter and summer ($p = 0.428$; 0.757).

(b) Control over heating and cooling

Duo office occupants indicated that they had the most control over the heating in their workspace (m = 2.88) whereas 8Plus office occupants perceived themselves to have had the least control (m = 1.88). A significant difference was observed between the mean scores of their perception ($p < 0.001$). The post hoc test showed that statistically, the perception of 2–4, 5–8 and 8Plus office occupants, differed significantly from that of Solo office occupants ($p < 0.001$) and Duo office occupants ($p < 0.001$). There was no significant difference between the response from Solo and Duo offices occupants ($p = 0.714$); 2–4 and 5–8 office occupants ($p = 0.999$).

Similarly, for control over cooling, occupants in Duo offices showed that they had the most control (m = 2.79) whereas occupants in 8Plus offices showed to have had the least control (m = 2.03). A significant difference was also observed between the mean scores of occupants' perception for this variable ($p < 0.001$). The Tukey post hoc test showed that the perception of occupants over the control of cooling in 2–4 offices ($p = 0.037$) and 8Plus offices ($p < 0.001$) differed significantly from those in

Solo offices. Control over cooling was perceived significantly higher in Solo offices (m = 2.56) than those in 2–4 (m = 2.31) and 8Plus (m = 2.03) offices.

The test also showed a significant difference between the opinions of occupants in 2–4 offices ($p < 0.001$), 5–8 offices ($p = 0.004$) and 8Plus offices ($p < 0.001$) and those in Duo offices. Perceived control over cooling was significantly higher in Duo offices (m = 2.79) compared with those in 2–4 (m = 2.31), 5–8 (m = 2.38), and 8Plus (m = 2.03) offices.

No difference was found between Solo and Duo office occupants ($p = 0.259$); 2–4 and 5–8 office occupants ($p = 0.978$).

(c) Air quality in summer and winter

For air quality, Solo office occupants were most satisfied in winter and summer (m = 4.61; 4.45). Occupants in 5–8 offices were least satisfied in winter (m = 4.43) and occupants in 8Plus offices were least satisfied with the air quality in summer (m = 4.30). No significant difference was observed between occupants' perception of air quality in winter and summer.

(d) Control over ventilation

Duo office occupants reported that they had the most control over ventilation in their offices (m = 3.12) while 8Plus office occupants had the least control over these factors (m = 2.19). Post hoc test showed that the perception of occupants in 2–4, 5–8 and 8Plus offices differed significantly from those of Solo office occupants ($p < 0.001$). Perceived control over ventilation in Solo offices (m = 3.06) was significantly higher than those in 2–4 (m = 2.57), 5–8 (m = 2.62) and 8Plus (m = 2.19) offices. The test also showed a significant difference between the opinions of occupants in 2–4 offices ($p = 0.000$), 5–8 office ($p = 0.001$) and 8Plus offices ($p = 0.000$) and those in Duo offices. Perceived control over ventilation in Duo offices (m = 3.12) was significantly higher than those in 2–4 (m = 2.57), 5–8 (m = 2.62) and 8Plus (m = 2.19) offices. The perception of occupants in 8Plus offices differed significantly from all the other groups of occupants ($p < 0.001$). No significant difference was found between the perceptions of Solo and Duo offices over ventilation control.

(e) Noise

Regarding noise in the workplace, occupants in Duo offices were most satisfied with the noise level in their offices (m = 4.80), whereas occupants in 8Plus offices were the least satisfied with noise (m = 4.24). Significant differences were found amongst occupants perception of noise overall ($p < 0.001$). The post hoc test indicated that the mean score for Solo offices occupants' responses were significantly higher than those in 8Plus office occupants ($p = 0.001$). Also, the mean score of Duo office occupants was significantly higher than those from 2–4 office ($p = 0.002$), 5–8 office ($p = 0.012$) and 8Plus office ($p = 0.000$) occupants regarding satisfaction with noise levels. No significant difference was observed when comparing the other office types in pairs.

(f) Control over noise

For control over noise, occupants in Solo offices had the most perceived control while occupants in 8Plus offices had the least perceived control. A significant difference in mean scores were also observed ($p < 0.001$). Post hoc test showed that occupants in 5–8 offices ($p = 0.003$) and 8Plus offices ($p = 0.000$) scored perceived noise significantly lower than those occupants in Solo offices. The test also showed a significantly higher perceived control over noise in Duo offices than those in 8Plus offices ($p < 0.001$). Furthermore, occupants in 8Plus offices were noted to differ from all other groups of occupants ($p < 0.001$). When comparing the other pairs of office types, no significant differences were observed.

(g) Lighting

Solo office occupants were most satisfied with the lighting in their offices (m = 5.33) while 2–4 office occupants were least satisfied (m = 5.11). A significant difference in mean scores was found for lighting overall ($p = 0.048$) between Solo office and 2–4 office occupants ($p = 0.035$) only. No other groups showed a significant difference in the mean scores of their opinions.

(h) Control over lighting

For control over lighting, occupants in Duo offices reported having the most control (m = 3.81) while occupants in 8Plus offices had the least control (m = 2.46). Overall, a significant difference in mean scores was observed when comparing the five groups ($p < 0.01$). Post hoc test showed that occupants in 2–4 offices, 5–8 offices and 8Plus offices had significantly lower perceived control over lighting when compared to Solo offices (m = 3.78) and Duo offices (m = 3.81). The test also showed perceived lighting control was significantly lower in 8Plus offices when compared to all other groups of occupants ($p < 0.001$). No significant difference observed between Solo and Duo office occupants ($p = 1.000$); 2–4 and 5–8 office occupants ($p = 0.219$).

Table 2. Mean Scores of variables analysed.

Office Buildings' Variables Tested	Mean Satisfaction Rating on Variables										p-value
	Solo Office		Duo Office		2–4 Office		5–8 Office		8Plus Office		
	m	SD	m	SD	m	SD	m	SD	m	SD	
Furniture	5.36	1.302	5.27	1.306	5.18	1.407	5.25	1.350	5.13	1.398	0.001
Space at Desk	4.50	1.346	4.43	1.334	4.38	1.393	4.42	1.414	4.19	1.832	0.000
Temperature Overall in Winter (TW)	4.63	1.738	4.69	1.671	4.55	1.677	4.50	1.725	4.60	1.714	0.428
Temperature Overall in Summer (TS)	4.42	1.778	4.32	1.793	4.40	1.720	4.41	1.713	4.47	1.717	0.757
Air Overall in Winter (AW)	4.61	1.631	4.57	1.619	4.51	1.575	4.43	1.682	4.47	1.643	0.151
Air Overall in Summer (AS)	4.45	1.690	4.30	1.670	4.33	1.598	4.42	1.606	4.43	1.620	0.376
Noise Overall	4.51	1.791	4.80	1.729	4.38	1.734	4.43	1.727	4.24	1.712	0.000
Lighting Overall	5.33	1.546	5.12	1.568	5.11	1.595	5.22	1.542	5.20	1.555	0.048
Overall Comfort	5.00	1.511	4.93	1.466	4.77	1.438	4.80	1.457	4.82	1.454	0.007
Productivity	5.31	1.614	5.20	1.637	5.13	1.734	5.13	1.729	5.01	1.705	0.001
Health	4.06	1.232	3.92	1.230	3.94	1.283	3.98	1.401	3.86	1.344	0.006
Control over Heating	2.72	2.095	2.88	2.063	2.31	1.766	2.35	1.766	1.88	1.516	0.000
Control over Cooling	2.56	1.966	2.79	1.948	2.31	1.747	2.38	1.734	2.03	1.585	0.000
Control over Ventilation	3.06	2.151	3.12	2.189	2.57	1.870	2.62	1.828	2.19	1.708	0.000
Control over Noise	2.48	1.674	2.40	1.627	2.29	1.538	2.25	1.450	2.00	1.402	0.000
Control over Lighting	3.78	2.279	3.81	2.212	3.19	2.126	2.95	1.925	2.46	1.843	0.000

Note: m represents mean values; SD represents standard deviation; p-value represents correlation significance.

Furniture

The occupants rated the usability of the furniture provided at their desks or work area (1 = very poor; 7 = very good). The highest satisfaction score with furniture was observed in Solo offices (m = 5.36), while 8Plus offices obtained the least scores (m = 5.13). The mean score of responses related

to furniture was observed to be significantly different when comparing mean scores of the five groups ($p = 0.001$).

(i) Adequacy of Space

The occupants also rated the adequacy of space at their desks or work areas (1 = too little; 7 = too much). Similar to their perception of furniture, occupants in Solo offices scored the space at their desks the highest (m = 4.50), while occupants in 8Plus offices scored the space at their desks the lowest (m = 4.19). The mean score of responses in regard with space at desks was observed to be significantly different when comparing mean scores of the five groups ($p < 0.001$).

4.2. Objective 2: Health, Overall Comfort and Productivity

In terms of health, occupants in Solo Offices felt that they were the healthiest in their office spaces (m = 4.06), most comfortable (m = 5.00) and more productive (m = 5.31) as a result of the environment in their buildings (Table 2). On the other hand, occupants in 8Plus offices felt that they were the least healthy when in their office spaces (m = 3.86) and most unproductive (m = 5.01).

There were significant differences in the perception of occupants of health conditions ($p = 0.006$), overall comfort ($p = 0.007$) and the perceived productivity ($p = 0.001$). Post hoc comparisons using the Tukey HSD test showed that for overall comfort, the perception of occupants in 2–4 offices ($p = 0.015$) and 8Plus offices ($p = 0.023$) differed significantly from occupants in Solo offices. No other group's perception differed significantly. Regarding perceived health, a significant difference was observed only between occupants in Solo offices and 8Plus offices ($p = 0.001$). The same was observed for reported productivity between Solo office and 8Plus office occupants ($p = 0.001$).

Effect on Behaviour

The occupants were asked whether they changed their behaviour because of the conditions in the building. The responses were closely divided as 52.4% of the occupants answered "Yes" while 47.6% of the occupants answered "No" (Table 3).

Table 3. Effect on Behaviour.

Effect on Behaviour	Yes (%)	No (%)
Solo office	45	55
Duo office	49	51
2–4 office	46	54
5–8 office	47	59
8Plus office	54	46
Total	47.6	52.4

4.3. Objective 3: The Impact of Office Layout on Perceived Overall Comfort and Productivity

To investigate the extent of influence of IEQ variables (Temperature Overall in summer and winter, Air quality Overall in summer and winter, Lighting and Noise) had on occupant overall comfort and productivity across the five office layout types, a multiple regression analysis was undertaken.

Reported in the R square and F change of the multiple regression analysis, the R square explains the measure of the amount of variance the dependent variables (comfort and productivity) that the independent variables (IEQ variables and personal control) account for when taken as a group. The F change calculates the degree of difference between the groups i.e. the larger the F change, the more effect the independent variables have on the dependent variable. The purpose was to identify the variables that had more impact on perceived comfort and productivity in the different types of office layouts.

a. Impact of IEQ variables on overall comfort and productivity in all five office layouts

As shown in Table 4, the R square scores showed that as a group, satisfaction with IEQ variables in all the office types accounted for more of the variance in overall comfort (over 50%) than in perceived productivity (less than 40%).

The F change shows that the perception of occupants in 8Plus offices on IEQ variables had the largest impact on overall comfort and productivity (F = 239.610; 78.927 respectively). Temperature in summer did not prove to have a significant impact on the overall comfort of occupants in all the office types. For productivity, noise was the only IEQ variable that had a significant impact on their perception.

Table 4. Impact of IEQ variables on overall comfort and productivity in all five office types.

Office Space	Overall Comfort				Productivity			
	R Square	Adjusted R Square	F-value	P-value	R Square	Adjusted R Square	F-value	P-value
Solo office	0.587	0.584	180.857	<0.001 (Ex TS = 0.325)	0.242	0.235	38.810	Only Noise and AS (<0.001)
Duo office	0.603	0.594	64.899	<0.001 (Ex TS = 0.238)	0.283	0.265	16.214	Only Noise (0.001)
2–4 office	0.548	0.543	110.879	<0.001 (Ex TS = 0.800)	0.238	0.230	27.119	0.000 (Ex TW = 0.662; TS = 0.789)
5–8 office	0.536	0.530	94.805	<0.001 (Ex TS = 0.071)	0.349	0.341	42.458	<0.001 (Ex TW = 0.082; AW = 0.740)
8Plus office	0.547	0.544	239.610	<0.001 (Ex TS = 0.071)	0.288	0.284	78.927	<0.001(Ex TS = 0.064)

b. The magnitude of the impact of individual IEQ variables on overall comfort and productivity

The impact of occupants' perception of individual IEQ variables on overall comfort differed amongst the groups of occupants (Table 5). For occupants in Solo offices, air quality in summer had the most impact on the overall comfort (F = 855.207) whereas air quality in winter had the most impact for the rest of the office layouts. For perceived productivity, Noise had the largest impact for occupants in Solo (F = 204.756), 2–4 (F = 121.438) and 8Plus (F = 352.197) offices. Air quality in winter was most impacting for occupants in Duo offices while in 5—8 offices (F = 75.580), air quality in summer had the largest impact (F = 127.580)

Table 5. The level of impact of IEQ variables on overall comfort and productivity.

Office Space	F-value for Overall Comfort					
	TWoverall	TSOverall	AWOverall	ASOverall	Lighitng	Noise
Solo office	507.161	366.317	762.476	855.207	220.135	237.644
Duo office	163.184	81.324	213.956	158.527	78.431	132.861
2–4 office	228.329	166.281	316.806	262.551	269.328	272.894
5–8 office	232.841	146.078	397.871	233.237	169.930	155.234
8Plus office	624.984	405.003	950.927	689.272	350.074	337.902

Table 5. *Cont.*

	F change for productivity					
Solo office	102.685	92.354	161.022	144.021	64.450	204.756
Duo office	63.063	36.731	75.187	48.555	18.109	56.126
2–4 office	73.896	57.680	111.544	89.274	59.093	121.438
5–8 office	61.796	113.471	112.522	127.580	96.856	116.488
8Plus office	174.304	152.327	258.272	237.506	119.879	352.197

5. Discussion

The findings described above provided interesting evidence of the effect of the spatial office environment on occupants' perception of their wellbeing and productivity. Generally, the findings show that the perception of occupants coincided with the number of occupants in the office. For instance, occupants who shared with fewer people (Solo and Duo offices) had similar views about their comfort and productivity as well as those who shared with more people (5–8 and 8Plus offices).

a. Objective 1

Objective 1 of this study was explored by comparing the mean scores of satisfaction ratings on occupants' office environment regarding IEQ and office fit out. The findings showed that except for temperature in summer, the perceived satisfaction of occupants in Solo and Duo offices was statistically higher for nearly all IEQ variables examined. These group of occupants also had the most personal control over the IEQ in their office environment. This finding supports numerous studies that showed the benefits of cellular and private offices on occupants' wellbeing. For example, Hauge et al., [35] pointed out that an employee in a single office is more in control of the temperature, ventilation, lighting and noise than occupants that are tied to their workplaces in open layouts.

It was interesting to note that occupants in 8Plus office reported the highest satisfaction with the overall temperature in summer. Common sense would suggest that occupants in this type of office space are likely to be uncomfortable with the temperature in summer as a result of the number of people in the space. However, a likely reason for this outcome may be that open-plan office tend to be more airy due to the larger space. During summer, the rise in temperature often requires more circulation of air which is desirable to cool down the space. In support of this notion, occupants in 8Plus office rated the air quality in summer higher than other occupants (m = 4.43) following closely after those in Solo offices (m= 4.45). It was also noted that both groups of occupants rated the air quality and temperature in summer highest amongst others.

It was also shown that occupants in Solo and Duo offices were most satisfied with the suitability and the usability of the furniture in their desk areas. However, occupants in 8Plus offices were least satisfied. This finding supports a past study by Kim and de Dear [36] wherein the authors observed that the biggest impact on overall satisfaction was the amount of space available to occupants. The finding of our study can also be explained by the fact that due to greater autonomy available for occupants in Solo and Duo offices, it is easier to customise fit outs and furniture for those occupants to suit their preference. Whereas, in open-plan offices, the furniture are often designed to fit an anticipated pattern of use for the occupants in the same space. This often results in less opportunity for unsatisfied users to seek alternative furniture options.

An interesting finding is the perception of occupants in Duo offices on noise levels and control over ventilation lighting and temperature in their offices. While past studies suggest that occupants in open-plan offices are less satisfied with noise [14,37], our findings indicated that occupants do appreciate some level of interaction(or noise) while at work. As shown in the findings, occupants in Duo offices were more satisfied with the overall noise levels than those in Solo offices. Our study supports that of Haynes [38] who noted that interaction is a significant positive component in an office environment. Duo office occupants reported to have more control over the ventilation, heating,

cooling and lighting in their offices than other types of offices. The intriguing question is why would occupants in Duo offices have more control than those in Solo offices?

b. Objective 2

Regarding Objective 2, our study showed that occupants who shared an office with fewer people (Solo and Duo offices) felt that they were healthier, more productive and overall more comfortable in their offices than those in open-plan offices (5–8 and 8Plus offices). These results were in line with some recent studies on open-plan office spaces [8,39,40]. Bernstein and Turban [8] noted that face-to-face interaction patterns decreased by 70% when occupants were moved from cellular offices to open-plan offices. The authors maintained that open-plan architecture appeared to trigger a natural human response to socially withdraw from officemates and interact instead over email and instant messaging. Otterbring et al., [40] found a negative relationship between open-plan offices and occupants' wellbeing and satisfaction while Richardson et al., [39] observed that open-plan offices were not beneficial to occupants' health.

Interestingly, the question on behavioural change as a result of the office environment did not produce a distinctive variance in opinions amongst the groups of occupants as all occupants reported to either change their behaviour (47.6%) or not (52.4%) as a reaction to the office environment. Specifically, it could be deduce that more occupants did not change their behaviour. It may be worth mentioning that in respect to the type of office spaces, 8Plus office was the only type where more occupants reported to have changed their behaviour as a result of the office environment (54%). While the significance of this result (regarding the focus of our study) is supportive of the earlier findings, the degree of score is quite debatable because a sizeable number of occupants reported to not change their behaviour as a result of the environment (46%). A plausible reason could be that despite the dissatisfaction with the office environment, these occupants tend to have unconsciously adapted to the environment overtime without a noticeable change in behaviour—a research area for further studies.

c. Objective 3

Objective 3 of this study was addressed by analysing the predictive power of IEQ factors on perceived comfort and productivity. The findings showed that the level of satisfaction with the IEQ variables in the office significantly predicted the perceived overall comfort of all occupants except for the temperature in summer. The perception of occupants in 8Plus office had the largest impact on perceived overall comfort followed by those in Solo offices highlighting the significance of their diverse characteristics. Air quality in winter had the largest impact and highest predictive power for overall comfort in all types of office layouts except in Solo office. Air Quality in summer had the highest predictive power for overall comfort in Solo offices.

Interestingly, it was observed that the IEQ variables that predicted comfort did not predict perceived productivity. For instance, the variables as a group could not account for up to 40% of the variance in perceived productivity. Also, there was inconsistency in the significance of individual IEQ variable on productivity. This finding contributes to the ongoing debate on the relationship between a comfortable and productive office environment. While many studies suggest that a comfortable environment equates to a productive one, this finding supports research that argues otherwise. Could it be that there are non-IEQ factors that contributed to perceived productivity as opposed to comfort as suggested by past research? There is a growing awareness of the significant impact of the behavioural/social environment (such as interaction and distraction) on occupants' productivity [38,41]. For example, Byrd & Rasheed [41] showed that non-IEQ factors such as being undervalued at work, poor management, workload, wellbeing and loss of sleep were more important to productivity than IEQ factors. This significance of this finding across a dataset of 5,000 occupants across the world becomes more intriguing in case of office types (cellular or open-plan); since it determines what factors contribute to a productive environment for each type of office environment.

It is worth noting that the perception on noise level was the only variable that predicted the perceived comfort and productivity across all the groups of occupants. This supports past studies of noise in open-plan offices suggesting the importance of acoustics in an office environment [42,43].

For instance, Seddigh et al., [44] noted that improved acoustical conditions could lead to less cognitive stress and disturbances in open-plan offices.

The focus of this paper is office users/occupants' evaluation of their work environments. As such, the findings of this study are considered to be subjective.

6. Conclusions

With the ongoing debate on open-plan versus cellular office spaces, this study provides empirical evidence from 5000 occupants in 67 commercial and institutional buildings across the world. It highlights the effect the type of office environment has on occupants reported satisfaction with the indoor environment and ergonomics, comfort, health and productivity. This study showed that occupants in Solo and Duo offices perceived higher satisfaction with their environment, better health and productivity than those in 5–8 and 8Plus offices.

The importance of occupants having personal control over the IEQ was emphasised in this study. It was noted that occupants in Solo and Duo offices had more control over IEQ than those in 5–8 and 8Plus offices. This suggests the need for innovative acoustic improvements in office design.

The indoor environment quality factors that predicted comfort were observed to not predict productivity. Noise was the only IEQ factor that had predictive power for both comfort and productivity in all the office spaces. This suggests that factors that significantly affect comfort do not necessarily influence productivity.

Further studies could investigate the influence of other aspects of the work environment such as social factors on occupants' perception of comfort and productivity as this study has indicated the influence of non-IEQ factors on the perception of occupants. Also, the perception of occupants in institutional and commercial buildings could be compared to identify what type of office that is preferred.

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