A DILEMMA BETWEEN BUILDING INDOOR ENVIRONMENT PREFERENCES AND OCCUPANT ENERGY BEHAVIOURS

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Often, building occupants compromise the energy savings of the building when they modulate their comfort through occupant behaviours. Therefore, this study identifies the relationships among indoor environmental conditions, comfort preferences, and occupant behaviours to improve future energy modelling works on occupant behaviour in buildings. A self-administered online questionnaire survey was conducted using a purposive sample of 46 occupants selected from five educational office buildings. Results show that the occupants' satisfaction with indoor environmental quality (IEQ), user-centred building controls, and furniture arrangements across the three office types: private, shared, and open-plan office has a similar value except for thermal comfort in winter and/or summer, ventilation in winter, acoustic comfort, and access to lighting control. The results also show the relationships of 17 occupant behaviours with 15 comfort preferences, where that highlights that the occupants were highly concerned about satisfying individual indoor air quality (IAQ) and thermal comforts through their behaviours rather than to save energy and follow management guidelines. Furthermore, IAQ and control over thermal and IAQ related parameters such as heating, cooling, and ventilation are highly correlated with the occupant behaviours, and these could be considered as primary predictors of occupant energy behaviours. These relationships of IEQ and user-centred building controls with occupant behaviours could be utilized to enhance future occupant energy behaviour modelling approaches and pinpoint the energy wasteful behaviours.

Keywords: controls; comfort; energy; indoor environment; occupant behaviours

INTRODUCTION

With the rapid urbanisation and industrialisation, most people spend 90% or more of their time indoors and in confined spaces including time spending on living, learning, working, and travelling (Abdulaali *et al.,* 2020). Therefore, indoor environments have widespread effects on building occupants' health, well-being, satisfaction, and performance (Wong, Mui and Tsang 2018). In recent years, many studies have investigated the Indoor Environmental Quality (IEQ) of buildings in terms of occupant satisfaction in comfort and productivity (Rasheed Rasheed, Khoshbakht and Baird 2019). Key factors of IEQ are derived through those studies and include

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Weerasinghe, A S, Rasheed, E O and Rotimi, J O B (2021) A Dilemma Between Building Indoor Environment Preferences and Occupant Energy Behaviours *In:* Scott, L and Neilson, C J (Eds) *Proceedings of the 37th Annual ARCOM Conference,* 6-7 September 2021, UK, Association of Researchers in Construction Management, 794-803

thermal comfort, indoor air quality (IAQ), visual comfort, acoustic quality, and spatial comfort (Bluyssen 2019).

Usually, unconscious and conscious actions of humans to control the physical parameters of the surrounding built environment to their preferences are possible when they are in discomfort and trying to create a comfortable indoor environment (Nicol and Humphreys 2002). As Schweiker (2010) defined, these unconscious and conscious actions refer to occupant energy behaviour, where the occupants are trying to achieve the desired personal comfort level using various strategies. Building occupants influence the indoor environment through their presence and by modifying the building's systems and elements (Bluyssen 2019) such as opening and closing windows, adjusting blinds, adjusting thermostat temperature, and turning the air conditioning on or off (Hong *et al.,* 2017). The research by Fabi *et al.,* (2012) and Hong *et al.,* (2017) showed that occupant behaviours (OB) highly influence the increase of building energy demand. The contribution of OB is extremely significant as the difference between predicted and actual energy use is mainly due to the way that occupants behave, their presence, and occupancy levels in buildings (Gaetani, Hoes and Hensen 2016). The reliability of simulation results depends on the quality of assessment of occupants' influence on buildings (Royapoor and Roskilly 2015). Therefore, the occupants should not compromise the energy savings of the building when they modulate their comfort.

Driven by these it is believed that the design and control of indoor environmental conditions, occupant comfort preferences, and occupant energy behaviours are inter-connected to each other. A proper balance between those aspects is significant to reduce the energy wastage due to occupants while realising energy saving potentials of occupants. However, the focus on empirical studies is still limiting to IEQ parameters such as thermal, IAQ, visual, and acoustics and their influence on occupant energy behaviours. For example, a study by Amasyali and El-Gohary (2016) in their study highlighted the association between OB and the level of satisfaction of the building occupants. Another study by Bavaresco *et al.,* (2021) has connected the main sources of discomforts into windows, blinds/shades, thermostats, and lighting in office settings. Their study only addressed triggers such as temperature, air, light, view, noise, and access to the thermostat as driving factors of OB.

However, review studies often suggest other indoor environmental factors such as furnishings, the spatial layout of workspaces, and the access for controlling heating, cooling, lighting, etc. as important (Fabi *et al.,* 2012; Weerasinghe, Rasheed and Rotimi 2020). For example, shared work areas and open-plan workstations also show a greater impact on occupants due to the unwanted noise, disturbances, lack of storage space, privacy, and no control over the indoor environmental conditions (McElroy and Morrow 2010; Mesthrige and Chiang 2019). Onyeizu (2014) identified that occupants who have control over the temperature were highly satisfied with the thermal comfort of the space. To this end, OB and comfort preferences in different types of offices may further be expanded integrating indoor environmental conditions: thermal, IAQ, visual, acoustics, spatial comforts, and user-centred designs such as access to control indoor environmental parameters.

In the context of New Zealand, the studies conducted on office environments pointed out that the occupants prefer air-conditioned spaces over naturally ventilated spaces to fulfil their thermal comfort preferences (Rasheed *et al.,* 2017) and acoustic improvements in office design to reach their perceived comfort level. However, the relationship among indoor environmental conditions, comfort preferences, and OB are merely addressed in the context of New Zealand. Driven by this motive, this study explores the existing indoor environmental conditions including IEQ, user-centred designs and furniture arrangements, and the occupants' satisfaction with these conditions. The paper also explores the prominent occupant energy behaviours and the occupant comfort preferences of office buildings in New Zealand. More importantly, the study compares the occupant's satisfaction with the indoor environment across different types of workplace arrangements such as private room, shared room, open-plan office, and the relationship of OB with indoor environmental conditions.

METHODS

Oftentimes, quantitative methods such as surveys and questionnaires have been used to understand occupants and their energy-related behaviours and construct building energy models (Day and O'brien 2017). Moreover, Hong *et al.,* (2017) showed survey method can provide more insights into OB compared to experiments and field observations in terms of various factors that drive behaviours. In the current study, a survey method was used to explore the occupant's satisfaction with indoor environmental conditions, prominent occupant energy behaviours, and occupant preferences across different working arrangements. An online questionnaire was designed and administered through Qualtrics Survey software. This is a popular data collection platform used in contemporary research studies. The questionnaire has consisted of four sections. Sections 1 included occupants' background information such as the job role, gender, occupancy period of the current workspace, and the characteristics of the workspace. In section 2, participants were asked to mention the office type that workstations are arranged in the building. Section 3 has consisted of questions related to occupants' satisfaction and they were asked to rate the satisfaction in terms of thermal comfort and ventilation in summer and winter, visual comfort and acoustic comfort, user-centred designs, and furniture arrangement. Section 4 focused on OB and comfort preferences. All measures related to satisfaction were estimated by a Likert-type item of 1-7 (completely dissatisfied, mostly dissatisfied, somewhat dissatisfied, neither satisfied nor dissatisfied, somewhat satisfied, mostly satisfied, completely satisfied). The participants for the survey were conveniently recruited from the university staff and PhD students regularly occupying office spaces from five buildings in a University in New Zealand. Emails were sent to potential respondents of 257 inviting them to complete the survey. A total of 46 valid responses from building occupants in office spaces were collected. Likert-type items have a clear rank order without an even distribution, therefore, the data generated from these types of questions are considered ordinal data which has a non-normal distribution of data (Guerra, Gidel and Vezzetti 2016). Therefore, frequency analysis and Spearman rank correlation were used to analyse the data. The Statistical Package for Social Sciences (SPSS) version 27 was used to conduct these analyses.

Cronbach’s alpha reliability analysis was conducted to test the internal consistency of the instrument that shows how well the survey measures what the study wants to measure. In the current study, it was applied to questions relating to satisfaction on indoor environment conditions such as IEQ, user-centred designs, and furniture arrangements. Reviewing empirical studies, Taber (2018) explained that alpha reaching 0.70 value is a sufficient measure of internal consistency. The overall

Cronbach's alpha value for the current occupant survey is 0.716 which shows an acceptable level of reliability for 13 constructs of this study.

RESULTS AND DISCUSSION

Five buildings in a university were selected for the current study that available office spaces for the staff and PhD students who are regularly occupying the buildings. The number of occupants in the buildings ranged between 12 to 96 were mostly occupied by staff. Demographic information of participants is presented in Table 1. There were more males than females in the selected sample. Most participants had worked in their present work area for a year or more than a year. Furthermore, most participants were in shared offices that accommodated two to five people, and both staff and students occupy the three types of office spaces; private room, shared, and open plan. The current study compares the difference of occupant's satisfaction level and practice of OB across diverse types of workplace arrangements such as private room, shared room, open-plan office.

Table 1: Demographic Information of Participants

Demographic Info		Staff	Students	Total
Gender	Male	12	13	25
	Female	16	5	21
Years in Present Work Area	Less than a year	11	10	21
	A year or more	17	8	25
Office Type	Private Room	13	5	18
	Shared Space	12	8	20
	Open-plan Office	3	5	8
Location of Workstation	Close to a window within 5 feet	23	11	34
	Centre of the office	2	2	4
	Close to an exterior wall within 5 feet	3	5	8

Occupants' Satisfaction with IEQ across Private, Shared, and Open-plan Offices

Discomforts in indoor environmental quality and access to user control can be considered as drivers of OB. Therefore, building occupants were asked to rate their satisfaction on thermal comfort and ventilation in summer and winter, visual comfort and acoustic comfort, user control availability on heating, cooling, ventilation, lighting, and noise, and arrangement of workstation furniture and equipment (i.e. desk, chair, footrest, telephone, document holder and printer, etc.). The percentage of frequency values of the occupant satisfaction with IEQ, user-centred building controls, and furniture arrangement is shown in Fig 1.

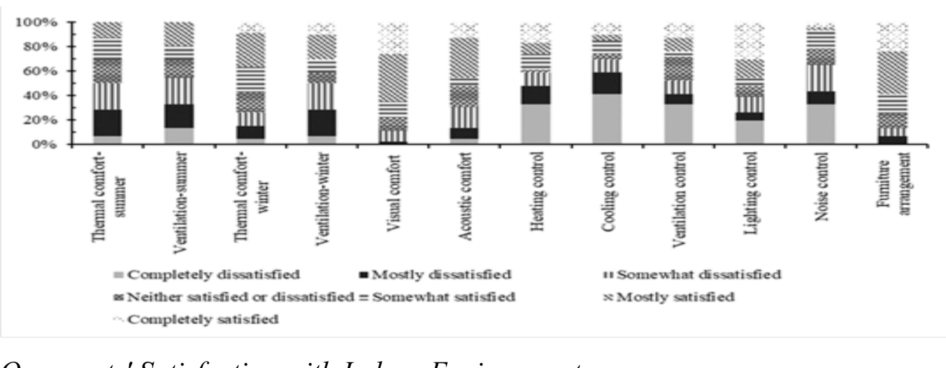

Fig 1: Occupants' Satisfaction with Indoor Environment

Overall, 50% or more than 50% of the building occupants rated their satisfaction on thermal comfort in winter, visual comfort, acoustic comfort, user control in lighting, and furniture arrangement as "somewhat satisfied" or higher. Going further, it is also important to discuss the satisfaction with IEQ comfort, user control, and workstation furniture and equipment across different office types.

Occupants' satisfaction must be comprehensively understood to improve IEQ, user-centred designs, and arrangement of workstation furniture and equipment across all types of office spaces. Literature identified that occupants' satisfaction can be vary due to the concerns over sharing of building systems and controls. The median values of the satisfaction rating given by the building occupants across different office types: private, shared, and open-plan office are presented in Table 2.

Table 2: Occupants' Satisfaction Across Different Office Types

Indoor Environmental Condition	Median Value of Satisfaction			Indoor Environmental Condition	Median Value of Satisfaction		
	Private	Shared	Open plan		Private	Shared	Open plan
Visual comfort	6	6	6	Ventilation-winter	5	3	3
Furniture arrangement	6	6	6	Ventilation-summer	4	3.5	3
Thermal comfort-winter	5	4.5	6	Heating control	4	2.5	2
Acoustic comfort	5	4	6	Ventilation control	4	3.5	1
Lighting control	4	6	4	Noise control	3	2.5	3
Thermal comfort-summer	3	3.5	5	Cooling control	2	1.5	2

As seen from Table 2, visual comfort and furniture arrangement were rated as the highest satisfaction across three office types. There was a similarity in the satisfaction rating by the occupant across private, shared, and open-plan offices in terms of visual comfort and furniture arrangement. Additionally, the building occupants in open-plan offices were highly satisfied with thermal comfort in winter and acoustic comfort, while the occupants in shared offices have rated higher satisfaction in access to lighting control. Furthermore, the same parameters in the other office types were received a somewhat satisfactory or neutral opinion from the occupants. However, this is contrary to the previous studies that support the occupants in shared work areas and open-plan offices are less satisfied due to unwanted noises and no control over the indoor environmental conditions (McElroy and Morrow 2010; Mesthrige and Chiang 2019). Thermal comfort in summer and ventilation in winter were rated as somewhat satisfactory in open-plan offices and private rooms, respectively, but the same received somewhat dissatisfactions across other office types. However, other parameters: ventilation in summer and user control in heating, ventilation noise, and cooling were rated as dissatisfied or neutral across all three types of offices.

Overall, these results indicate that occupants across the three office types: private, shared, and open-plan office have a similar value of satisfaction except for thermal comfort in winter and/or summer, ventilation in winter, acoustic comfort, and access to lighting control. Since occupants' satisfaction across different office types is mostly similar, overall occupants' satisfaction with IEQ, user-centred controls, and workstation furniture and equipment can be considered as triggers or drivers of OB and comfort preferences, irrespective of office type. The next section analysed these OB and comfort preferences in the office environment.

Occupant Behaviours and Comfort Preferences

Referring to previous studies Bavaresco *et al.,* (2021), Hong *et al.,* (2017) and Weerasinghe, *et al.,* (2020), 15 OB and 15 comfort preferences were given as a multiple-choice question in the questionnaire. The building occupants were asked to select the OB they practice while working and the expected changes from these behaviours. These OB and comfort preferences are summarised in Table 3 with the frequency (%) distribution and the ranks were assigned in descending order.

Table 3: Occupant Behaviours and Comfort Preferences

Occupant behaviour	Frequency (%)	Rank	Comfort Preferences	Frequency (%)	Rank
Open/close windows	78.3	1	To let in fresh air	76.1	1
Drink hot/cold beverages	73.9	2	To feel cooler	71.7	2
Adjust clothing	65.2	3	To feel warmer	71.7	3
Open/close internal doors	63.0	4	To increase air movement	67.4	4
Turn lights on/off	58.7	5	To air freshness	60.9	5
Adjust shades and blinds	56.5	6	To avoid outdoor sounds	43.5	6
Adjust computer screen brightness	54.3	7	To feel healthier	30.4	7
Adjust personal heaters	50.0	8	To avoid glare	28.3	8
Turn off the computer monitor	47.8	9	To have access to outside view	26.1	9
Open/close external doors	43.5	10	To save energy	23.9	10
Moving through spaces	34.8	11	To increase artificial lighting	17.4	11
Report discomfort	32.6	12	To increase daylighting	17.4	12
Adjust portable/ceiling fans	28.3	13	To experience the variety of the outdoor climate	10.9	13
Adjust room air conditioning unit	17.4	14	To hear outdoor sounds	6.5	14
Adjust thermostats	10.9	15	To follow management guidelines	4.3	15

As seen from Table 3, opening/closing windows and drinking hot/cold beverages were ranked the highest (more than 70%) among the other OB. Further, adjusting clothing, opening/closing internal doors, turning lights on/off, adjusting shades and blinds, adjusting computer screen brightness, and adjusting personal heaters were practiced by 50% or more occupants and ranked, respectively. Additionally, adjusting the computer desk was newly added by one of the occupants. Considering the comfort preferences, most of the building occupants (76%) were expected to let in the fresh air through open windows, while a considerably less percentage of occupants were also expected to feel healthier, access to outside view, and experience the variety of the outdoor climate by opening windows. Another considerable percentage of occupants (71%) were expected to feel cooler or warmer depending on the temperature they experience, which was achieved through drinking hot/cold beverages, adjusting clothing levels, and adjusting personal heaters. Other expectations were to increase air movement and air freshness and to hear outdoor sounds through opening internal/external doors and to avoid outdoor sounds by closing internal/external doors. Although most of the building occupants are visually satisfied, they are expecting to avoid the glare by adjusting shades/blinds and computer screen brightness, But, the considerable percentage of the occupants highlighted turning lights on/off, although the concern on increasing artificial and daylighting is reduced. Most of the occupants were expected to improve comfort conditions through their occupant behaviours, while 32% of the occupants report the discomforts to the building management. However, adjust portable/ceiling fans, room air conditioning units, and thermostats have received a considerably less percentage (10%-30%) due to the limited availability and accessibility to control these systems. Only very few occupants were expected to save energy and follow management guidelines through their OB, while most of the occupants were concerned about individual comfortability.

This reinforces the OB association with indoor environmental conditions as presented in previous studies irrespective of office type. For example, Amasyali and El-Gohary (2016) explained that OB such as adjusting thermostat, portable/permanent heaters, room air conditioner, portable/ceiling fans, and open/close doors are associated with thermal comfort. Furthermore, open/close windows and doors, and use/adjust the humidifier are linked to indoor air quality. Similarly, Bavaresco *et al.,* (2021) found that open/close windows and HVAC are related to thermal, acoustic, and IAQ; adjust blinds and shades to visual and thermal comfort; while turn lighting on/off is affected by visual comfort. Additionally, the current study provides insights into drivers of drink hot/cold beverages, adjusting clothing, adjusting computers, moving through spaces, and report discomfort. Majority of occupants trying to reach their IAQ and thermal comfort preferences via most of OB due to the lack of self-reported satisfaction with these parameters and their user control. The findings highlight the buildings' inability to perform up to the expectations of the occupants. However, further studies are required to analyse the other social, physiological, and psychological drivers influencing OB in office buildings and compare those with IEQ and user-centred design and control triggers. Further, occupants were asked to rate the frequency of OB practice and how influential are these behaviours towards the comfort preferences. Fig 2 shows the frequencies of the rating by occupants.

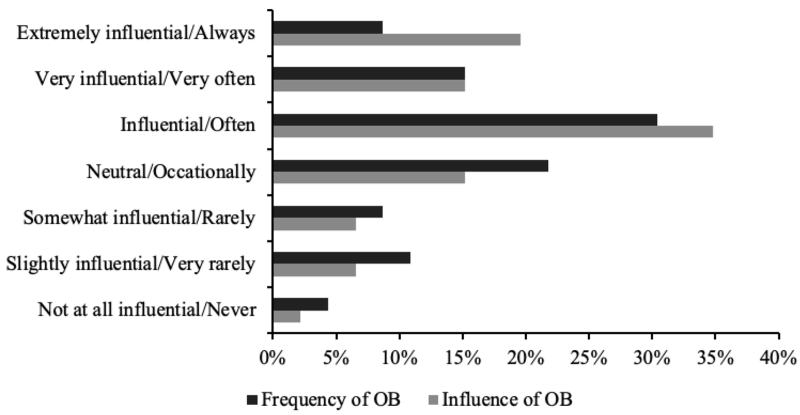

Fig 2: Occupant Rating on Influence and Frequency of OB practice

As shown in Fig 2, in terms of frequency of the practice of OB, most of the building occupants rated "often" or more. Similarly, the influence of OB on the desired effect was rated as "influential" or more. Overall, the influence of OB and frequency of OB were rated by 60% and 54% of the building occupants as influential or often, respectively.

Finally, the Spearman rank correlation was run for the dependent variables: influence of OB and frequency of OB, and independent variables: IEQ, user-centred control, furniture arrangement, and office type. The Spearman correlation coefficient (r) measures the strength of a relationship, that can take values from -1 to +1. According to, Weerasinghe, Ramachandra and Rotimi (2020) there is no fixed definition of correlation strength. This study used the thresholds given by Ricciardy and Buratti (2015) such as $0 < r < 0.3$ (Weak), $0.3 < r < 0.7$ (Moderate), and $r > 0.7$ (Strong). A significance level < 0.05 was considered to determine whether the relationships are significant. However, significant correlations have appeared only for the influence of OB, these results are summarised in Table 4.

Table 4: Relationship between Influence of OB and Indoor Environmental Conditions

	Influence of OB	Significance (p-value)
Thermal Comfort in winter	0.448*	0.002
Ventilation in Winter	0.540*	0.000
Thermal Comfort in Summer	0.390*	0.007
Ventilation in Summer	0.561*	0.000
Visual Comfort	0.347*	0.018
Acoustic Comfort	0.357*	0.015
Heating control	0.645*	0.000
Cooling control	0.576*	0.000
Ventilation control	0.531*	0.000
Lighting control	0.385*	0.008
Noise control	0.378*	0.010
Furniture Arrangement	0.261	0.080
Frequency of OB	-0.149	0.323
Office Type	-0.142	0.348

As shown in Table 4, most of the independent variables show a moderately significant relationship with the influence of OB, except furniture arrangement, office type, and frequency of OB. Furthermore, heating control has the strongest relationship (0.645) with the influence of OB, which was closely followed by cooling control, ventilation in summer, ventilation in winter, and ventilation control. Overall, IAQ and control over thermal and IAQ related parameters have the strongest bond with the OB. This further cement the major influence of thermal and IAQ related drivers on OB in office buildings. This finding agrees with that of Bavaresco *et al.,* (2021) and extends the findings relating to the influence of user-centred designs and control over building systems to OB in offices. Onyeizu (2014) suggested that occupants should be given more control over the IEQ in their local environment to achieve greater comfort.

CONCLUSIONS

The purpose of this study was to uncover the relationships among indoor environmental conditions such as IEQ, user-centred design and furniture arrangements, comfort preferences, and occupant behaviours for integrating these relationships in future energy modelling of buildings. Results show that more than 70% of occupants were satisfied with visual comfort and furniture arrangement in office buildings. Further, indoor environmental quality (IEQ), user-centred building controls, and furniture arrangements across the three office types: private, shared, open-plan office had a similar value of satisfaction except for thermal comfort in winter and/or summer, ventilation in winter, acoustic comfort, and access to lighting control. Additionally, dominant behaviours and comfort preferences were identified based on the frequency distribution, which showed that dominant behaviours: open/close windows, drink hot/cold beverage, adjust clothing, open/close internal doors were to satisfy individual IAQ and thermal comfort preferences. Furthermore, IAQ and control over thermal and IAQ related parameters such as heating, cooling, and ventilation are highly correlated with the occupant behaviours, and these could be considered as primary predictors of occupant energy behaviours. These relationships of IEQ and user-centred building controls with occupant behaviours could be utilized to enhance future occupant energy behaviour modelling approaches to reduce the gap between predicted and actual energy use, while pinpointing the occupants' energy wasteful behaviours. A better understanding of OB and comfort preference driven by subjective aspects of occupants would support policy makers, designers, and building managers to optimise the building energy performance from a building's design and construction stage. This study based on surveying 46 occupants in office buildings serves as the pilot study of research that aims to develop an interdisciplinary framework for occupant energy behaviours. Therefore, the limitations of the study (i.e., purposive sampling, sample size) will be addressed in the extended research.

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