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HEALTH OF GREEN BUILDING OCCUPANTS: BOTH INDOOR AND NEIGHBORHOOD ENVIRONMENTS MATTER

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Commonly adopted green building standards, such as LEED and BEAM PLUS, tend to focus on the sustainable performance of buildings. There is a lack of comprehensive consideration on the associations between building environment and health of occupants, let alone the impact of neighborhood environment on the occupants. This study thus aims to investigate the impact and interplay of indoor and neighborhood environment on health of green building occupants. To achieve this aim, two green buildings, which locate in contrasting neighborhood environment in Hong Kong, are selected for case study. Based on the data collected by post-occupancy evaluation (occupant health), indoor environment assessment (thermal comfort, indoor air quality, ventilation, visual comfort, and acoustic comfort) and neighborhood environment assessment (neighborhood building density, neighborhood building height, neighborhood green area, and neighborhood cleanliness) through questionnaire survey, the results reveal that the relationship between indoor environment and occupant health is significantly moderated by neighborhood building height. The results lay foundation on how the green building standards can be further developed to enhance occupant health by taking neighborhood environment into account.

Keywords: Indoor environment, Occupant health, LEED, Sustainability.

1 BACKGROUND

The three pillars of sustainability are economic, sustainability and social. Therefore, the people's aspect definitely deserves more attention so as to achieve the ultimate goal of sustainability of green buildings. However, commonly adopted green building assessment schemes in Hong Kong, such as LEED and BEAM Plus, tend to focus mainly on the energy-saving performance of buildings in terms of efficient usage of resources like water, energy, building materials, and so on. There is a lack of consideration on the associations between indoor building features (e.g., thermal comfort, visual comfort, acoustic comfort, etc.), and the health of occupants, let alone the impact of neighborhood environment on green building occupants. Most of the assessment methods are universal in which buildings with different neighborhood environments are assessed in the same way without considering the intimate interactions between indoor and external environment, and more importantly, the impact of these interactions on green building occupants.

Previous studies on green buildings and occupants often focus on how the indoor environment affects the satisfaction of occupants, while those focusing on health of occupants are rare. In addition, given that neighborhood environment can influence indoor environment (e.g., the influence of outdoor temperature on indoor temperature) and, thereby, the occupants;

neighborhood environment should be taken into account when assessing the impact of green buildings on occupants.

This study thus aims to investigate the impact and interplay of indoor building environment and the neighborhood environment on the health of green building occupants. To be more specific, it is hypothesized that the neighborhood environment significantly moderates the indoor environment-occupant health relationships in a green building.

2 INDOOR AND NEIGHBORHOOD ENVIRONMENTAL HEALTH

Previous studies have identified various indicators for indoor environmental quality, including indoor air quality (IAQ), ventilation, thermal comfort, acoustic condition, visual condition, and so on. IAQ focuses on the concentration of different air pollutants, such as carbon monoxide, nitrogen dioxide, sulfur dioxide, volatile organic compounds, ozone, non-methane hydrocarbons, particulates sulfates and nitrates, formaldehyde and radon, in the indoor environment (Yocom 1982). Previous studies have indicated that these air pollutants can cause bronchoconstriction, asthma symptoms, lung cancer, irritation to eyes, visibility problems, headaches, dizziness and even fatal poisoning in occupants (Ghiaus *et al.* 2006, Raub *et al.* 2000). On the other hand, poor ventilation has also been identified as the antecedents of various respiratory diseases, including severe acute respiratory syndrome (Gao *et al.* 2009, Wang *et al.* 2010). Luminance level has also been found to influence the visual comfort of occupants (Osterhaus 2005). Furthermore, IAQ and thermal comfort have also been found to be significantly correlated to Sick Building Symptom (SBS) Index (Roulet *et al.* 2006b). SBS refers to the symptoms experienced by occupants, such as headaches, lethargy, dry eyes or throat, itchy or watery eyes, etc., as stimulated by the building environment (Roulet *et al.* 2006a). The relationship between indoor environment and occupant health have long been recognized.

However, its neighborhood environment can influence indoor environment of a building. For instance, previous studies have indicated the impact of urban neighborhood characteristics, in terms of land-use ratio and thermal mass, on indoor air temperature of buildings (Mirzaei *et al.* 2015). On the other hand, air pollutants emitted from vehicles in busy district may cause greater indoor air pollution through permeable building façade (Ghiaus *et al.* 2006, Roulet 2001). Hence, it can be postulated that the indoor environment should not only affect health of occupants in green buildings. The interaction between indoor and outdoor environment should also be taken into account.

3 RESEARCH METHODS

To achieve the research aim, a case study of two BEAM Plus platinum awarded, institutional buildings in Hong Kong are conducted. The two buildings are located in areas with contrasting environmental characteristics in terms of neighborhood building height, neighborhood building density, cleanliness, and so on. The first one is the S H Ho Academic Building (SH) of the Hang Seng Management College in Sha Tin, New Territories; where more landscape can be found in the neighborhood. The second one is the Jubilee College (JC) of the Open University of Hong Kong in Homantin, Kowloon, which is surrounded by tall and high-dense buildings. The neighborhood environment of the two buildings is visualized in Figures 1 and 2.

Data are collected based on post-occupancy evaluation of occupant health, indoor green building quality and neighborhood environment quality via questionnaire surveys. The survey is designed to have four main parts, namely, background information, indoor environment quality (including thermal comfort, indoor air quality, ventilation, visual comfort, and acoustic comfort; CBE 2015), neighborhood environment quality (including building density, building height,

green area and environmental cleanliness, Fornara *et al.* 2010) and health of occupants (Roulet *et al.* 2006). Respondents are invited to answer the questions based on a 7-point likert measurement. Statistical analyses are then conducted, using the software of SPSS, for comparing the performance of the two buildings and to investigate the hypothetical relationships between indoor environment, neighborhood environment, and health of occupants.

Figure 1. Neighborhood environment of JC.

Figure 2. Neighborhood environment of SH.

Purposive sampling is adopted in this study, in which respondents are recruited only if they are: i) students studying, academic staff or administrative staff working in the case buildings, and ii) who are 18 years old or above, at the time when the study was conducted. In sum, 100 responses are collected from the survey study, in which 50 come from SH and 50 comes from JC respectively. Majority of the respondents are students (90%), followed by administrative staff (7%) and academic staff (3%). More than 65% of the respondents spent more than ten hours in the building in a week.

4 ANALYSES AND RESULTS

4.1 T-Test of Indoor, Neighborhood Environment and Health of Occupants in the Cases

Independent-samples t-test is performed to compare the mean scores of indoor environment, neighborhood environment and health of occupants in the two cases. As shown in Table 1, the scores of all indoor environment factors (i.e., thermal comfort, indoor air quality, ventilation, visual comfort and acoustic comfort) and the three-neighborhood environment factors (i.e., neighborhoods building density, neighborhoods building height, and neighborhood green area) of SH are significantly higher than that of JC ($p<0.01$). Table 2 shows that occupants in JC suffer significantly runnier nose than their counterpart ($p<0.01$). Hence, the moderating role of the three-neighborhood environment factors, which found to have significant differences in the two cases, will be further investigated.

4.2 Hierarchical Multiple Regression Analyses

Moderation refers to the impact of the interactions between an independent variable (indoor building features in this case) and a moderator (neighborhood environment) on a dependent variable (health of occupants). To investigate the moderating effects of neighborhood environment on the indoor environment-occupant health relationships, hierarchical regression analysis is performed (Aiken and West 1991). Three models are developed for the moderating effects of neighborhood building density, neighborhood building height and neighborhood green area, respectively. In the first step of each model, the five indoor environment variables are added, namely thermal comfort, indoor air quality, ventilation, visual comfort, and acoustic comfort. In the second step, a neighborhood environment moderator is added. Subsequently, in

the final step, the interaction terms of the moderator and the five indoor environment variables are added to test the hypothetical moderating effects of the neighborhood environment factors on the predictive effects of the five indoor environment factors on occupant health. Among the three hypothetical moderators, only neighborhood building height is found to have a significant moderating effect on the visual comfort-occupant health relationship (sig. F change < 0.05). Table 3 summarizes the results of the hierarchical regression analyses for neighborhood building height. The values of R2 and adjusted R2 are shown at the bottom of the model.

Table 1. T-test results of indoor environment and neighborhood environment in the two cases.

	Satisfaction	Mean Building		SD Building		Sig. (2-tailed)
		SH	JC	SH	JC	
Indoor	Thermal comfort	5.18	2.88	1.16	1.21	**0.000***
	Indoor Air Quality	5.70	3.30	1.16	1.25	**0.000***
	Ventilation	5.42	3.60	1.05	1.29	**0.000***
	Visual Comfort	6.30	3.90	0.81	1.11	**0.000***
	Acoustic Comfort	5.64	3.58	1.06	1.25	**0.000***
Outdoor	Neighbourhood building density	5.18	4.18	1.25	1.22	**0.001***
	Neighbourhood building height	5.22	4.18	1.09	1.08	**0.000***
	Neighbourhood green area	4.90	3.62	1.39	1.32	**0.000***
	Neighbourhood cleanliness	5.12	4.68	1.33	1.19	0.085

5 DISCUSSION

The study findings confirm that occupants in green building with the same building usage, similar building age, and the same green qualification (i.e., BEAM Plus Platinum award) can have significantly different level of comfort on the indoor building environment and health (refer to Tables 1-2). This acts as a platform for the investigation of the moderating effects of neighborhood environment on indoor building environment and health of green building occupants. The study results indicate that neighborhood-building height moderates the effect of visual comfort on occupant health (refer to Table 3). Visual comfort refers to 'a subjective condition of visual well-being induced by the visual environment' (ECS 2002). Building occupants prefer to work under natural lighting than electric lighting (Edwards and Torcellini 2002). Flickering in electric lighting affects occupants' comfortability and health; while natural lighting is essential in preventing fatigue of occupants (Edwards and Torcellini 2002). Natural lighting has also been found to be a key antecedent of psychological health. Occupants sitting or working near windows with higher natural light penetration are more motivated, calm and in better mood than their counterparts sitting further away from windows (Hwang and Kim 2010). Tall neighborhood buildings block sunlight from entering a green building (Steemers 2003, Ünver *et al.* 2003), affecting occupants' visual comfort and thus, health.

Table 2. T-test results of health of occupants in the two cases.

		Mean Building		SD Building		
	Frequency	**SH**	**JC**	**SH**	**JC**	**Sig. (2-tailed)**
Building-related symptom	Dry Eye	4.74	4.56	1.70	1.50	0.576
	Itchy or watery eyes	5.04	4.82	1.44	1.62	0.476
	Blocked or stuffy nose	4.24	4.72	1.85	1.57	0.164
	Runny nose	3.82	4.72	1.62	1.55	**0.006***
	Dry throat	4.38	4.46	1.71	1.27	0.791
	Lethargy or tiredness	3.58	3.88	1.90	1.45	0.377
	Headaches	5.18	5.64	1.51	1.63	0.146
	Dry, itching or irritated skin	5.12	5.64	1.62	1.55	0.105
	Sneezing	4.24	4.44	1.66	1.30	0.504
	Breathing difficulties	5.92	5.96	1.34	1.35	0.882
Overall	*Overall Health*	4.63	4.88	1.18	1.05	0.251

Table 3. Hierarchical regression for the moderating effect of neighborhood building height.

Dependent Variable	Independent Variable	Model					
		1		2		3	
		Standardized Coefficients	Sig.	Standardized Coefficients	Sig.	Standardized Coefficients	Sig.
		Beta		Beta		Beta	
Overall Health	Thermal Comfort (TC)	0.159	0.288	0.171	0.259	-0.258	0.627
	Indoor Air Quality (IAQ)	0.021	0.918	0.045	0.830	0.631	0.531
	Ventilation (V)	0.222	0.219	0.190	0.308	0.560	0.493
	Visual Comfort (VC)	-0.039	0.835	-0.086	0.664	**1.571**	**0.040***
	Acoustic Comfort (AC)	-0.167	0.318	-0.173	0.303	-1.419	0.076
	Neighbourhood Building Height (BH)			0.088	0.486	**1.109**	**0.021***
	TC x BH					0.552	0.416
	IAQ x BH					-0.537	0.704
	V x BH					-0.624	0.632
	VC x BH					**-2.763**	**0.025***
	AC x BH					1.542	0.167
R-square		0.058		0.063		0.177	

6 CONCLUSION

In sum, the study provides empirical support that: i) Occupant health is significantly different in buildings with the same green grading but located in areas with different external environments;

and ii) The relationship between visual comfort and occupant health is significantly moderated by neighborhood environment, in terms of neighborhood building height. The results of this study lay solid platform on how the current green building assessment schemes can be further developed to enhance occupant health by taking neighborhood environment into account. For example, taking location as one of the assessment criteria in green building assessment method in which neighborhood building height should be of particular focuses. Meanwhile, the study results also push forward the development of academic research in the field and lay foundation for further objective studies.

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