Research Article

The environment of open-plan workspaces: space utilization, user satisfaction, and environmental measures

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ABSTRACT

This paper aims to identify how indoor environmental factors are associated with space utilization and user satisfaction in flexible open spaces in an academic building. Data were collected through mixed methods, including a survey, observation, and objective environmental assessment. The mixed-methods assessed users' environmental perception and satisfaction, types of activities, types of users (group vs. individual), lighting, noise, temperature, humidity, and carbon dioxide level in five open-plan spaces with different furniture configurations. The subject spaces were identified as underutilized because there was a mismatch between the demand and supply of furniture and spatial settings. Even though all subjective spaces were open-plan settings, students preferred space with shared-furniture or a combination of different types of furniture with individual-oriented furniture only. The findings of the study suggest a reevaluation of space planning and programming for increased spatial efficiency. The users were generally satisfied with the subject spaces, although ambient environmental measures were slightly outside the industry standards. The present study provides evidence of user preferences of spatial settings based on the type of users (group vs. individual) and type of activities performed in the space (i.e., paper-based work, laptop, phone/tablet, eating, resting, talking).

Keywords: open space; space utilization; user satisfaction; environmental satisfaction; indoor environmental quality

1. Introduction

Spaces in higher education are for various uses such as teaching, learning, studying, research, socializing, support, and general use (Janks, Lockhart, & Travis, 2012). As the teaching and learning method changes from traditional lecture to informal learning, the open spaces play an important role as a supportive space for academic achievement (Sullivan, 2010). Students can spend their time in open spaces such as lobbies, hallways, lounge space, and public areas for meeting, talking, socializing, and working in a small group. The environment of spaces such as indoor environmental quality, space settings, and furniture configuration is important as it can enhance or diminish students' productivity. However, attention to spaces in higher education has tended to occur in libraries and classrooms rather than open spaces, and has not focused on physical arrangements (Temple, 2008). There is a lack of evidence on the importance of physical environments to students' satisfaction and productivity.

According to APPA - Leadership in Educational Facilities (2013), universities in the U.S. spent $2,073 per full-time equivalent (FTE) per year on average for building operation costs in 2009. Efficiency in space use is one of the primary considerations in campus space planning and strategy because it directly affects capital investment opportunities and operation costs (Ibrahim, Yusoff, & Sidi, 2011; Janks et al., 2012). As students prefer spaces that meet their needs (Webb, Schaller, & Hunley, 2008), it is essential to understand which space types and configurations in open spaces are appropriate for different student activities. Understanding space use can improve not only space utilization (Ibrahim et al., 2011; Janks et al., 2012) but also students' campus experience and academic performance (Lavy, Daneshpour, & Choi, 2019; Peker & Ataöv, 2020).

Students' learning and intellectual tasks are similar to knowledge work. Knowledge workers have high autonomy for their jobs and often proactively choose their activities, tools, locations, and work environment to perform their work (Duffy & Powell, 1997). Although there are differences between open-plan environments in higher education and corporate offices, such as age and responsibility for work, the effects of open-plan space on cognitive tasks have similarities (Braat-Eggen et al., 2017; Kang, Ou, & Mak, 2017). Studies on open-plan learning environments in higher education are limited compared to workplaces.

Many studies have examined the impacts of various environmental conditions of open-plan offices, such as spatial layouts and indoor environmental quality, on the occupants' satisfaction and performance (Clements-Croome, 2006; Friedman, 2014; Peponis et al., 2007). However, there exists a lack of consensus regarding the effects of the open-plan office on occupants. Many previous studies have analyzed survey or interview data without considering objective data of built environments (Arundell et al., 2018; De Been & Beijer, 2014; Sandström et al., 2016). This paper proposes to combine quantitative and qualitative data to fill the gap of inconsistency.

This study aims to identify how indoor environmental factors are associated with space utilization and user satisfaction in the open-plan space, taking on a case study approach in a higher education building. This paper analyzes the patterns of space use and environmental satisfaction in open-plan environments in higher education. Three research questions are as follows: 1) Are the objective indoor environmental factors related to occupants' environmental satisfaction in open-plan design? 2) Is the user satisfaction with the indoor environmental quality associated with the overall environmental satisfaction? and 3) Are space use patterns associated with furniture configuration and furniture types in open-plan design? To answer these questions, this study uses mixed methods, both subjective and objective data from the survey, observation, and objective indoor environmental measurements.

2. Literature Review

2.1. Open-plan environments for students in higher education

Traditionally, teaching in higher education was mostly done by a unidirectional lecture in a classroom. However, teaching and learning have changed into more team-based or team project-based learning, which often requires collaboration outside the classrooms (Hamilton, 2009). As the way of teaching has changed, the learning space has been expanded. Along with this change, schools provide additional open-plan spaces that students can utilize. Students use open-plan spaces for various purposes, such as individual studies, team projects, resting, and social interaction. Open-plan spaces support students in actively communicating with each other, increasing productivity (Bryant, Matthews, & Walton, 2009; Lee, 2014), and enhancing health and well-being (DeClercq & Cranz, 2014; Lee, 2014).

Open-plan environments increase the opportunity for collaboration among users through spontaneous interactions, ultimately increasing the likelihood of innovation (Hoendervanger et al., 2019). The increased communication between users allows to share tacit knowledge (Nonaka, 1994); this is also applied to students in academic environments (Beckers, van der Voordt, & Dewulf, 2015; Lee & Schottenfeld, 2014). The frequency of communication and knowledge sharing is important because continuous learning and teaching are the significant factors influencing the quality and productivity of knowledge work (Arundell et al., 2018; Drucker, 1999).

It is noted that the prevailed acceptance of the impacts of open-plan layouts on the perceived performance and satisfaction are questioned by several studies (De Been & Beijer, 2014; Kaarlela-Tuomaala et al., 2009; Kim & de Dear, 2013). Kim and de Dear (2013) found a decrease in overall workspace satisfaction, visual privacy, and acoustic comfort in open-plan layouts. Another study found a decrease in productivity support, privacy, concentration, and satisfaction with indoor environments (De Been & Beijer, 2014). Different measurement methods and heterogeneity of office environments led to the difficulty in determining which specific layouts and furniture types have significant impacts on environmental satisfaction (Marquardt, Veitch, & Charles, 2002).

2.2. Furniture configurations in an open-plan layout

Furniture configuration, also known as furniture layout, is an important environmental component as it is related to privacy, interaction, acoustic quality (Lee, 2010) and consequently affects occupant satisfaction and productivity (Haynes, 2008; Rolfö, 2018). Marquardt et al.'s literature review (2002) highlights that adjustability and comfort of furniture and configuration are necessary to increase occupant satisfaction. Hassanain, Alnuaimi and Sanni-Anibire (2018) also include space arrangement and furniture as workplace performance indicators for user satisfaction. However, there is no conclusive general relationship between furnishings and their positive expected outcomes, fulfilling occupants' needs. In other words, there is no universal design of furniture that exactly satisfies a specific need. Individuals' responses to furniture design diverge based on institutions' culture where they are involved and personal preferences (Appel-Meulenbroek et al., 2011; Marquardt et al., 2002). Thus, there is a gap in understanding how users select and use space and furniture when introducing the open-plan design concept.

2.3. Indoor environmental quality (IEQ) and environmental satisfaction

A building's Indoor Environmental Quality (IEQ) can influence not only a building's energy consumption but also occupants' health, satisfaction, and productivity (Heinzerling et al., 2013; Zuhaib et al., 2018). IEQ can be assessed by objective and subjective measures of physical factors, such as air quality, lighting, thermal, and acoustic conditions. These IEQ measures, then, can be evaluated based on industry standards, such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)/ Chartered Institution of Building Services Engineers (CIBSE)/ U.S. Green Building Council (USGBC) Performance Measurement Protocols (PMP) and the European Standard EN 15251 (2007). PMP provides the criteria to assess the indoor environmental performance of operating buildings quantitatively and divides them into three categories – basic, intermediate, and advanced – according to the cost and accuracy of measuring the physical factors (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Chartered Institution of Building Services Engineers, and U.S. Green Building Council, 2010). The European Standard, EN 15251, provides the standard "for design and assessment of energy performance of buildings" (European Standard (EN), 2007), and it consists of four categories according to the level of expectations toward the built environments. This study utilizes the standards from EN 15251, Illuminating Engineering Society (IES), and ASHRAE.

This paper includes four IEQ factors: thermal comfort, visual comfort, acoustic comfort, and indoor air quality. Thermal comfort is a crucial factor that influences occupants' environmental satisfaction (Hongisto et al., 2016) and a building's energy consumption (Frontczak & Wargocki, 2011; Yang, Yan, & Lam, 2014). Thermal comfort represents how satisfied occupants are with the thermal environment (ASHRAE, 2013; Ole Fanger & Toftum, 2002).

Second, the quality of lighting in the workplace influences workers' health and well-being, leading to better work performance, reduced errors, and improved safety (van Bommel & van den Beld, 2004). EN 15251 suggests above 500 lux in office building settings. General Services Administration (GSA) uses the standard from Illuminating Engineering Society (IES), and IES recommends above 30 footcandles (fc) (322 lux) in the commercial office, including private and open offices.

Third, acoustic comfort affects occupants' work performance more in open-plan offices than in private offices due to distractions (Kaarlela-Tuomaala et al., 2009). There are two main streams of acoustic conditions: speech intelligibility and noise (Schlittemeier et al., 2008). Work performance is more related to speech intelligibility than the loudness of speech (Colle, 1980); open-plan offices are weaker in spatial attenuation than private offices (Kaarlela-Tuomaala et al., 2009). For instance, even though workers in the open office can communicate with each other, due to the weak attenuation, others can be easily distracted by conversation, and privacy could be invaded unintentionally. Noise plays as a physical stressor that decreases productivity (Gordon-Hickey & Lemley, 2012; Varjo et al., 2015) and physical well-being (Donald & Siu-Oi-Ling, 2001). In academic settings, noise disturbs students differently according to the types of tasks such as group activities, research, and exam study (Braat-Eggen et al., 2017; Kang et al., 2017). In this study, the survey items include occupants' acoustic satisfaction, and background noise is objectively measured. In the sound pressure level (SPL), EN 15251 suggests the acceptable ranges of Category II for landscape offices from 35dB to 45dB, and PMP indicates 50dB as a maximum level. ASHRAE Handbook: HVAC Applications recommends lower than 45dB in the open-plan offices (Owen, 2011).

Lastly, Jones (1999) claimed the need to investigate a clear causal relationship between the substances related to occupant health and indoor air quality (i.e., carbon dioxide (CO_2) levels and volatile organic compounds (VOCs) levels) influenced by building materials and activities. Many studies investigated the level of CO_2 produced by the high concentration of occupancy, human activities, and heating systems (Allen et al., 2016; Jones, 1999; Moriske et al., 1996). EN 15251 sets the acceptable ranges of the CO_2 levels, no higher than 500 ppm above outdoor CO_2 levels for Category II buildings. ANSI/ASHRAE 62.1 (2013) provides the standard for maintaining a steady-state CO_2 concentration in space, no higher than about 700ppm above outdoor air CO_2 level. In this study, the level of CO_2 was monitored.

2.4. Open-plan spatial density and utilization

Duval, Veitch, and Charles's (2002) comprehensively reviewed the literature on the relationship between environmental satisfaction and open-plan office density, including social density (number of occupants in the space) and spatial density (area (ft^2) per occupant). Duval et al. (2002) claimed that the high levels of both social and spatial density caused a lack of privacy and high distraction, which decreased the occupants' environmental satisfaction. When occupants were in similar spatial density space, the environmental satisfaction level was affected by the types of occupants' activities, such as quiet work or noise-producing interaction (Brill & Weidemann, 2001). This study assessed both the social and spatial density of the subject space. In the context of the spatial density, space utilization can be analyzed with the given space areas and capacity. Specifically, space utilization efficiency can be computed to check the requirement for a certain type of space by students as well as whether the design intention is met for space usage. Space utilization efficiency is also called space usage efficiency (Keaton & Johnstone, 2009). The computation is conducted according to the equations developed by the U.K.'s National Audit Office (NAO) (1996), and the details are provided in the following method section.

3. Methods

3.1. Site information

This study was conducted in a two-story academic building in the U.S., which had a total floor area of 10,667 sq. ft. The building has a hybrid layout, a mixture of enclosed offices, assigned open-areas, and unassigned open-areas. The building is facing east. The first floor has administration offices, a conference room, and a flexible open space, and the second floor has faculty and administration offices, conference rooms, and study areas for graduate students. There are no spaces assigned explicitly for classes. This building is mainly for the graduate students of the department, but the first floor is also open to everyone. The flexible open space (Area 1 in Figure 1) can be reserved for school events, conferences, and classes as well as used freely by students when it is not booked. Classes usually take place twice a week in the afternoon and evening in the flexible open space. Enclosed offices for faculty and administrative staff and assigned open-areas for graduate students were excluded from this study. Only the unassigned open-areas were included in this study, such as the flexible open space, the lobby area, and other open areas on both floors (Figures 1 & 2, plans are diagrammatic).

A mixed-methods approach was taken to answer the research questions: survey, objective environmental measures, and observation. In order to obtain systematic observation, the floor plans were divided into several

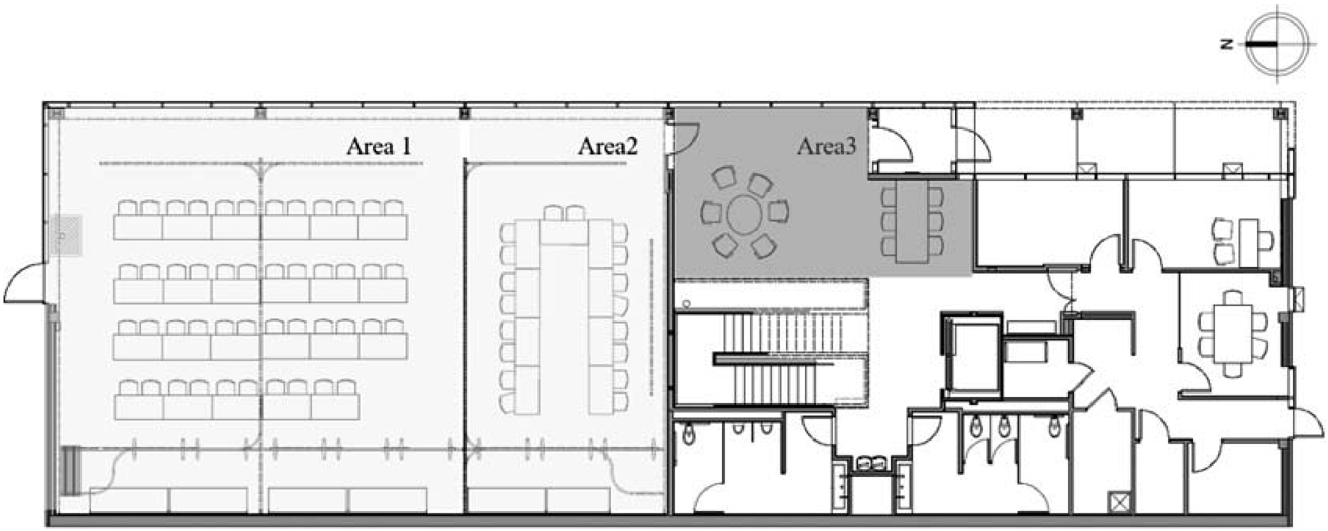

FIGURE 1.—First level floor plan

sections on each floor: three open-plan areas on the first floor and two open-plan areas on the second floor, each with different types of furniture configurations. There were three open-space areas on the first floor; area 1 and 2 had only individual desks (30" L x 60" W x 28.5" H), and area 3 provided only shared tables, including a high desk (37" L x 96" W x 42" H) and a round table (42" D x 23.5" H). The second floor had two areas; area 4 provided both individual desks and shared tables, and area 5 had only shared round tables. Individual desks were easily movable, while shared tables were hard to move. Each zone is marked on the floor plans according to furniture features of individual desks as light grey, shared tables as dark grey, and combination as dash pattern (Figure 1 & 2). Desks and tables were equipped with matching seats, movable office chairs with individual desks, lounge chairs, and bar stools.

3.2. Measurement 1: Survey

The survey was a self-report of user satisfaction in the subject space. The survey was conducted from April 9th to 19th, 2018. The survey and a flyer were distributed on the tables, and students voluntarily participated in the survey while using spaces. This study used a convenient sampling because the survey targeted primary users of the building, and the building serves about one hundred graduate students. Although some visitors outside the department were allowed to use the first floor only, the number of these users was minimal. The total number of survey participants was 30 out of about one hundred graduate students that the building is supposed to serve.

The survey consisted of three sections: space uses, user satisfaction, and demographic information. The survey questions focused on users' environmental and general

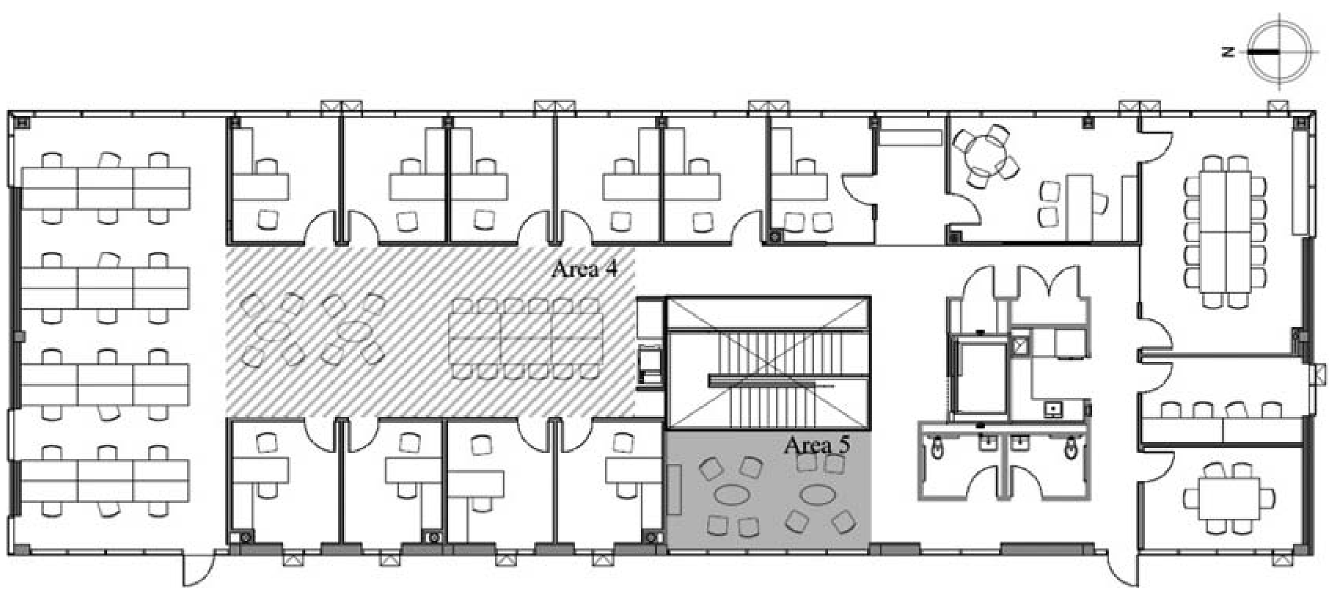

FIGURE 2.—Second level floor plan

TABLE 1.—Features of the spaces

Area	Floor	Furniture configuration	Furniture type	Area (ft^2)	Number of seats	Number of desks
1	1	Individual desk only	Individual Desk	1,764	46	23
2	1	Individual desk only	Individual Desk	882	18	9
3	1	Shared table only	Roundtable	441	6	1
			High desk	83	6	1
4	2	Combination	Roundtable	349	8	2
			Individual Desk	358	12	6
5	2	Shared table only	Round table	213	8	2

satisfaction with the space. The first section asked about space use, such as types of activities respondents were doing and the frequency of space use. The types of space use included studying alone (16 people, 26.67%), group work (12 people, 20%), studying alone but together (14 people, 23.33%), passing time/lounging (8 people, 13.33%), resting (4 people, 6.67%), miscellaneous work (2 people, 3.33%), presentation (2 people, 3.33%), and others (2 people, 3.33%) in multiple responses with a total of 60 choices. More than two-thirds of respondents used the space more than twice a week: two or three times (13 people, 43.33%), four times and more (7 people, 23.33%), once (4 people, 13.33%), and others (6 people, 20%).

The second section included questions to measure the user satisfaction level of the indoor environments and spatial features, including lighting, temperature, noise, background noise, distance to others, furniture configuration, and study supports, such as whiteboards, power outlets, and the Internet service, and overall environmental satisfaction, based on a 5-point Likert scale (1 = strongly dissatisfied to 5 = strongly satisfied). The survey also asked the level of thermal, noise, and visual comfort using a 5-point Likert scale.

The demographic section asked gender, age, position, ethnicity, and years in the school. Participants were asked to answer the survey placed on the desks. The total number of responses was 30, 53.33% males and 46.67% females, and the age was distributed to 18-24 (46.67%), 25-29 (23.33%), 30-34 (23.33%), and 35-39 (6.67%). The respondents were 73.33% of graduate students and 26.67% of undergraduate students (26.67%). The ethnicity of respondents was Asian (50%), White (33.33%), Black or African American (6.67%), others (6.67%), and Hispanic or Latino (3.33%). Most of the respondents had been at the school for one to two years (36.67%), followed by less than a year (30%), three to four years (26.67%), five years or more (3.33%), and others (3.33%). The scales and sources of all questions can be found in the appendix. The statistical analysis was conducted using R studio.

3.3. Measurement 2: Indoor environment quality (IEQ)

Objective environmental measures were used to assess the IEQ of the space. The physical environmental features were measured and recorded for noise (dB), temperature (°C), relative humidity (%), CO_2 (ppm), and illuminance (lux). The devices used to measure the physical environments were Extech 407732 Type 2 Digital Sound Level Meter for noise level (satisfying the standard by American National Standards Institute and International Electrotechnical Committee 651 type 2), Rotronic 1600 CP11 CO_2 Handheld Measuring Instrument for thermal and air quality (complied with EMC-Directive 2014/30/E.U. and RoHS-Directive 2011/65/E.U.), and AEMC CA811 Light Meter for illuminance level (certified by National Institute of Standards and Technology). To measure the vertical illuminance, the researchers sat on the chairs that were predetermined in each area and measured the vertical lighting on the level of the laptop monitor. The other environments were measured by laying the measures on the table or desk. The measurements were conducted every 1 hour from 12 pm to 5 pm between April 9th and 19th, 2018, which was the same period of the survey. The measurement locations are marked in Figure 3. The mean and standard deviation of the measurement are shown in Table 2.

3.4. Measurement 3: Observation

The observation aimed to investigate the patterns of space uses. The observation data were collected during two periods. The first term was the afternoon, from 12 pm to 6 pm, between April 9th and 12th, 2018, and the second term was the morning, from 10 am to 12 pm, between April 16th and 19th, 2018. The researchers checked and recorded the activities of the space users and the occupied seats every 15 minutes. Activities included paper-based work, using a laptop/tablet, using whiteboards, using a beam projector, eating or resting, and other behaviors if users' activities were not in the predetermined activities. Individuals in the subject space were non-identifiable, so individuals who stayed more than 15 minutes were recorded more than once. While recording the users' activities, the observers also took photos. The photos were used to cross-check with the observers' manual records for accuracy and supplement the limitations of hand-written records. The space use of the first floor was not observed or recorded when space was reserved for events or classes. A total of 526 people were observed, including 256 individuals working alone and 270 people in 97 groups. This study counted a group of two or more individuals as one data point, so a total of 353 cases of individual and group uses were used for data analysis. Among these users, a combined total of 59.30% of groups and individuals used the first floor, while 40.70% used the second floor. The types of tables used were round tables (51.21%), desks (26.42%), and high desks (22.37%). This study also observed user activities, which were sometimes

FIGURE 3.—Measurement and observation locations

happened simultaneously: using a laptop (61.19%), paper-based working (22.91%), eating and resting (22.64%), talking with someone else offline (5.23%), using a smartphone or a tablet (5.12%), and others (2.43%). Personal belongings occupied 2.16% of seats without an individual's presence.

Space utilization efficiency was calculated by the NAO's (1996) equations. NAO suggests the following equations to calculate the space utilization rates for higher education institutions. The utilization rate (3) is calculated by the space frequency rate (equation 1) and occupancy rate (equation 2). The space frequency rate is how often space is in use during the available time of the space. The occupancy rate is the average group size compared to space capacity for the hours when a room is in use. This method is usually applied in calculating the space utilization rates of classrooms that have planned classes. Although this research was not conducted in scheduled classrooms, since the observation and records were conducted in the fixed duration, such as from 10 am to 6 pm every 15 minutes, space frequency rate, occupancy rate, and utilization rate were computable and applicable. In this case, the maximum available hour was 64 hours; 8 hours per day from Monday to Thursday for two weeks.

$$\text{Space Frequency Rate} = \frac{\text{Number of hours space was in use}}{\text{Number of hours space was available}} \times 100 \quad (1)$$

$$\text{Occupancy Rate} = \frac{\text{Total number of persons occupying space}}{\text{Space Capacity X Number of hours space was in use}} \times 100 \quad (2)$$

$$\text{Utilization Rate} = \frac{\textit{Frequency Rate X Occupancy Rate}}{100} \quad (3)$$

4. Results

4.1. Results of Survey and IEQ

This study measured indoor environments to evaluate the quality of the subject spaces based on objective criteria: noise, temperature, humidity, CO_2, and light.

An ideal noise level from ASHRAE is 45dB, and the maximum acceptable level is 50dB. EN 15251 suggests between 35dB and 45dB for a comfort zone. The average

TABLE 2.—Indoor environmental quality measurement results (Mean (standard deviation))

	Area 1	Area 2	Area 3	Area 4	Area 5
Noise (dB)	49.67 (4.27)	50.85 (3.05)	52.87 (4.05)	48.08 (2.80)	51.09 (3.91)
Temperature (°C)	21.97 (0.47)	22.20 (0.49)	22.53 (0.80)	23.88 (1.11)	23.21 (0.87)
Humidity (%)	32.89 (7.73)	31.63 (7.24)	31.27 (6.62)	29.74 (6.25)	30.26 (6.34)
CO_2 (ppm)	524.42 (91.97)	519.82 (42.06)	577.74 (76.14)	612.58 (74.95)	636.41 (159.24)
Lighting (vertical, lux)	219.63 (76.85)	298.59 (363.41)	972.26 (671.54)	200.10 (142.93)	273.44 (63.16)
Lighting (plane, lux)	152.13 (71.85)	202.15 (164.67)	869.68 (430.02)	294.50 (100.46)	560.00 (140.18)

TABLE 3.—Satisfaction with the indoor environment (n = 30)

Environmental Quality	Min	Max	Mean	sd
Overall light	3	5	4.07	.64
Natural lighting	2	5	3.90	.96
Artificial lighting	2	5	3.57	.86
Temperature	1	5	3.43	1.10
Noise	1	5	3.47	1.14
Background noise	1	5	3.37	1.07
Furniture configuration	2	5	3.63	.93
Distance to others	1	5	3.60	.89
View to outside	2	5	3.87	.97
Study supports	1	5	3.37	1.03
Overall environmental satisfaction	2	5	3.87	.78

noise level of the subject spaces was between 48.08dB and 52.82dB. Notably, the noise level sometimes exceeded 50 dB because of the noise from HVAC equipment, although space was not occupied. The satisfaction levels with overall noise and background noise were 3.39 and 3.32 on a 5-point Likert scale. The respondents perceived the space comfortable (43.75%) and quiet (28.13%) with the noise from other people's conversation. The respondents reported that the space was comfortable (53.13%) and quiet (25.00%) with its background noise. Although noise level was also slightly higher than EN 15251 and ASHRAE Handbook criterion due to the noise from HVAC equipment and other sources, most of the respondents perceived the space as either comfortable or quiet.

The average temperature and humidity were between 21.97°C (71.55°F) and 23.88°C (74.98°F) and between 29.74% and 32.89%. The average of the respondents' perceived thermal comfort was -.25 within the range from -2 (too cold) to 2 (too warm). More than half of the respondents (59.38%) felt comfortable with the indoor temperature, yet 25% also reported that it was cold. Also, since humidity has a small effect on occupants' thermal sensation (EN 15251, 2007) and the average humidity was not too high or low, it could be considered in the comfort zone. The average level of CO_2 was between 519.82ppm and 636.41ppm, which was well within acceptable levels.

The lighting levels were measured on the desk plane and vertical to the desk plane. EN 15251 suggests above 500 lux as a visibility criterion for visual tasks in the office settings, and the lighting levels on desk plane in area 3 (shared table only), 4 (shared table only), and 5 (combination) were met EN 15251. Overall, the survey respondents were satisfied with the overall lighting level, showing the mean of 4.07 on a 5-point Likert scale. Some objective lighting measures were outside of the suggested range by EN 15251, ASHRAE, and ANSI. Although desk plane lighting levels on the shared table area and combination area, where the occupants used the most, satisfied the EN 15251 standard and IES standard, 20% of the survey respondents felt that spaces were too bright.

Based on the understanding of the building's indoor environment, this study a regression analysis to find the relationship between environmental factors and overall environmental satisfaction. A Pearson correlation table was reported in Table 4 to show how space-related variables and overall environmental satisfaction in the space were correlated with each other. Furniture configuration was correlated with overall environmental satisfaction, followed by a moderate correlation of distance to others, temperature, overall lighting, background noise, natural lighting, noise, and study supports. Noise and background noise were highly correlated, and the rest of the variables were moderately or less correlated.

A multiple regression analysis was performed to explore the relationship between environmental satisfaction variables and overall environmental satisfaction. In order to control demographic variables, the analysis added gender and age using dummy codes for categorical variables. Male was the reference group for gender, and 18 – 24 years old was the reference group for age. As the first step, all environmental components were included as independent variables; then, the multicollinearity test was conducted using the Variance Inflation Factor (VIF). The collinearity of noise (VIF = 6.90) and background noise (VIF = 7.70) turned out to be too high; thus, this analysis excluded the background noise variable, which had the highest VIF value, from the regression analysis. The final results of the regression analysis are shown in Table 5. Linearity, normal distribution, and homoscedasticity assumptions were tested with residuals and fitted plot, Q-Q plot, and Bartlett's test, respectively, and none of the assumptions were violated. The range of VIF was between 1.20 and 1.59, indicating

TABLE 4.—Pearson correlations (n = 30)

	1	2	3	4	5	6	7	8	9	10	11
1. Overall lighting	1										
2. Natural lighting	0.46*	1									
3. Artificial lighting	0.43*	0.28	1								
4. Temperature	0.35	0.53*	0.39*	1							
5. Noise	0.34	0.30	0.11	0.49*	1						
6. Background noise	0.27	0.21	0.10	0.50*	0.91*	1					
7. Furniture configuration	0.57*	0.27	0.36	0.36*	0.49*	0.52*	1				
8. Distance to others	0.35	0.39*	0.22	0.67*	0.73*	0.74*	0.57*	1			
9. View to the outside	0.18	0.32	0.30	0.15	-0.04	-0.05	0.40*	0.17	1		
10. Study supports	0.12	0.11	0.30	0.22	0.29	0.41*	0.36	0.39*	0.05	1	
11. Overall environmental satisfaction	0.50*	0.44*	0.27	0.51*	0.50*	0.52*	0.79*	0.67*	0.34*	0.54*	1

* $p < .05$

TABLE 5.—The result of the regression analysis: Overall environmental satisfaction regressed on satisfaction with environmental components

	Unstandardized Coefficient			
	b	S.E.	t	p
(Intercept)	0.30	0.77	0.39	0.70
Gender				
Female	0.20	0.21	0.96	0.35
Age				
24 – 29	0.04	0.24	0.17	0.87
30 – 34	0.36	0.32	1.12	0.28
35 – 39	0.38	0.40	0.95	0.35
Overall lighting	0.05	0.21	0.26	0.80
Natural lighting	0.20	0.14	1.44	0.17
Artificial lighting	-0.19	0.13	-1.48	0.16
Temperature	0.15	0.13	1.15	0.27
Noise	-0.08	0.12	-0.70	0.49
Furniture configuration	0.41	0.15	2.73	0.02*
Distance to others	0.14	0.17	0.80	0.43
View to outside	0.02	0.12	0.17	0.86
Study supports	0.22	0.10	2.21	0.04*

N = 30, $R^2 = .83$, Adjusted $R^2 = 0.69$, F (13, 16) = 5.92, $p<.05^*$
* $p<.05$

that there was no problem in multiple correlations among the predictors (VIF < 10). The model was statistically significant ($p<.05$) and accounted for 74.61% of the variance of the respondents' overall environmental satisfaction (Table 5). The furniture configuration and study support variables were statistically significant: overall environmental satisfaction increased by 0.52 and 0.23, respectively, when occupants' satisfaction of furniture configuration and study support increased by one unit. The other variables were not statistically significant.

4.2. Results of observation

A chi-square independence test was conducted to find the relationship between spatial configuration and space use patterns (Table 6). The analysis utilized 353 data points, excluding the emptied seats and other activities. This study categorized the type of uses into 1) individual focused work, 2) group work, 3) resting. Even though the case building was for academic purposes, many students used the building for resting between classes. Activity variable consisted of 1) focus (54.39%), 2) team (20.68%), and 3) resting (24.93%). On the other hand, the furniture configuration is categorized into 1) individual desks only (24.93%), 2) shared tables only (41.36%), and 3) combination (33.71%). In order to examine if there was a certain pattern of space use according to each activity, this study conducted a Pearson's Chi-squared test based on the contingency table of furniture configuration and activity in Table 6. As a result, users' activity was associated with where they sat ($X^2(4) = 77.116$, $p < .05$). People who performed focused work used all spaces evenly but slightly preferred the space with individual desks only. Over half of the people who worked as a team used combination space, and only 13% of them used the space with individual desks only. Lastly, over 75% of people who were resting preferred the configuration with the shared tables only.

The observation records were used to calculate the space utilization rate using equation 3 (Table 7). For example, the frequency rate of Area 1 was 51%, that the total minutes in use, 705, was converted to 11.75 hours, and then it was divided by the available hours of the space, 23. About the occupancy rate of Area 1, the number of occupants for hours used was 21.25. The number of occupants was recorded every 15 minutes; the initial total number of occupants was divided by four to convert minutes to hours. The average number of persons occupying space was divided by the space capacity, 46, and the number of hours the space was in use, 11.75, resulting in a 4% occupancy rate. The frequency rate (51%) was multiplied by the occupancy rate (4%) and divided by 100, resulting in 2.01% of the space utilization rate. In addition to the space utilization rate, the spatial density values were computed with the hourly average number of persons occupying space divided by the area of each space (Area 1 to 5). The spaces with individual desks had low spatial density. The average noise levels of the spaces, Areas 1 through 5, were 49.67, 50.85, 52.87, 48.08, and 51.09dB (Table 2). The noise levels in the spaces furnished with shared tables only (Area 3 and 5) were higher than those in the spaces with individual desks only (Area 1 and 2).

The results indicated that the spaces furnished with shared tables were more occupied than the spaces furnished with individual desks only were. Considering individuals used three types of furniture configuration evenly in Table 6, the results of Table 7 indicated that supply and demand for furniture were somewhat mismatched, especially the individual desk type.

6. Discussion

This study analyzed the relationship between objective indoor environmental quality and users' environmental satisfaction, the relationship between the users' environmental satisfaction and the overall environmental satisfac-

TABLE 6.—A contingency table of furniture configuration and activity (Frequency (%), n = 353)

		Furniture configuration			
Category		Individual desks only	Shared tables only	Combination	Total
Activity	Focus	69 (19.55%)	59 (16.71%)	64 (18.13%)	192 (54.39%)
	Team	11 (3.12%)	20 (5.67%)	42 (11.90%)	73 (20.68%)
	Resting	8 (2.27%)	67 (18.98%)	13 (3.68%)	88 (24.93%)
	Total	88 (24.93%)	146 (41.36%)	119 (33.71%)	353 (100.00%)

TABLE 7.—Space Utilization Rate

Area	Furniture configuration	Furniture type	Total minutes in use	Available hours	Frequency rate	Average # of persons occupying space (hourly)	Average spatial density (ft^2 per person)	Occupancy rate	Space utilization rate	
1	Individual desk only	Individual Desk	705	23	51%	21.25	975	4%	2.01%	
2	Individual desk only	Individual Desk	375	23	27%	7.5	735	7%	1.81%	
3	Shared table only	Round table/Bar	1605	32	84%	54.5	128	17%	14.19%	
4	Combination	Round table/Desk	315	32	16%	8.75	211	8.33%	1.37%	
5	Shared table only		Round table	1200	32	63%	44.25	96	28%	17.29%

tion, and the relationship between the space utilization patterns and furniture configurations.

IEQ and user satisfaction: Occupants' needs or complaints about indoor environments can be managed with objective measurements to prioritize the issues based on severity and importance. The occupant IEQ satisfaction levels were reviewed with the objective measurements in this study. This analysis enhances the understanding of the occupants' responses to environmental satisfaction concerning the measured IEQ values and suggests three implications. First, the average noise levels were higher than the standards (Table 2). Although the satisfaction levels of noise were positive, they are still low compared to other variables. The satisfaction levels with background noise and overall noise were 3.281 and 3.344, respectively. These results suggest considering noise prevention or absorption methods for the subject building, which are needed through building components, HVAC attenuation, and spatial layouts. As many corporate offices and academic facilities adopt open-plan layouts and noise is often directly related to distraction (Kaarlela-Tuomaala et al., 2009), they can implement sound-absorbing materials or noise policy among users to improve acoustic comfort (Virjonen, Keränen, & Hongisto, 2009). Second, the multiple linear regression analysis showed that the overall environmental satisfaction was related to the furniture configuration (Table 5).

Interestingly, the chi-square test of furniture configuration and activities indicated that people chose different furniture types according to their activities (Table 6). Also, there was a mismatch between the demand and supply of furniture configuration. These results emphasize that architects and facility managers should ponder occupants' activities because space users often do not utilize space and furniture as intended by design (Appel-Meulenbroek et al., 2011; Hassanain et al., 2018). Third, social and spatial density can provide facility managers and administrators with information for predicting overall environmental satisfaction and the satisfaction of distraction from the crowdedness (Hongisto et al., 2016; O'Neill, 1994). Spatial utilization and furniture configuration are discussed further in the following paragraphs.

IEQ and overall environmental satisfaction: The regression results showed statistical insignificance of all variables except furniture configuration and study support. This insignificance of the variables was contrary to previous studies that found the positive relationship between IEQ factors and overall environmental satisfaction (Veitch, Alnuaimi, & Sanni-Anibire, 2007).

Another notable result was that furniture configuration was related to overall environmental satisfaction. This result was consistent with the previous study conducted by Kim and de Dear in 2012. It was clear that an increase in satisfaction level of the furniture configuration was positively associated with the overall environmental satisfaction. The observation results also showed that people tended to have their preferred spaces depending on their activities. In other words, there was a possibility that people used their preferred places to increase satisfaction depending on their activity.

In addition to providing appropriate furniture configuration for students, it is also important to satisfy students' need for study supports. Supportive equipment for occupants' work, such as whiteboards, internet connection, and power outlets, were also related to overall environmental satisfaction. This result is consistent with a previous study on learning spaces in higher education; the learning spaces need to provide internet connection and tools such as whiteboards or additional screens in a workstation (Haug, 2008). Webb, Schaller, and Hunley (2008) also claimed that students preferred the space equipped with activity supportive artifacts.

Even though the previous studies provided evidence of low to moderate environmental satisfaction levels in the open-plan design, the subject building's satisfaction level was relatively high. The overall lighting was the highest satisfied component (4.062). Background noise (3.281) and noise (3.344) showed relatively low levels of satisfaction, but over 70% of occupants still perceived the space as comfortable or quiet with noise. When the environmental quality of basic factors, including access to daylight, temperature, noise, is within an acceptable range or higher than expected, there is no significant impact of IEQ factors on overall environmental satisfaction (Kim & de Dear, 2012, 2020). The IEQ satisfaction level in the subject building seemed in the acceptable range and had an insignificant association with the overall environmental satisfaction level. This implies that once the levels of IEQ factors, including temperature, humidity, CO_2, lighting, and noise, fall within the acceptable range, they are not significantly associated with overall environmental satisfaction. Regardless, the limited number of samples poses a possible statistical type II error, false negative.

Space utilization and furniture configuration: There are some possibilities for interpreting the results of space utilization rates with additional concepts. First, low space utilization rates lead to low spatial and social density levels. The spatial density is related to the perceived crowdedness of space, occupants' environmental satisfaction, and productivity (Oldham, 1988). Besides, a workspace with high spatial density infers a higher ambient noise level than a space with low spatial density. Therefore, the occupants in a high spatial density can be easily distracted (Hongisto et al., 2016). The spaces of the case building had low space utilization rates between 1.37% and 17.97% and low spatial density between 40.92 ft^2 per person and 975.39 ft^2 per person, and the occupants were satisfied with the low density showing a satisfaction level of 3.625 with distance to others. However, even though the space utilization rate and spatial density in the case building were low, the satisfaction with noise (3.344) and background noise (3.381) was low. This might be noise from machines and outside (Hongisto et al., 2016; Kang et al., 2017), which are not related to density. Even though the low utilization rate can reduce the possibility of noise from people, it is still important to control other noise sources to enhance the environmental satisfaction level.

As shown in the regression analysis in this study, furniture configuration is significantly associated with overall environmental satisfaction. Analyzing the configuration with space utilization and space use can help further increase satisfaction. Compared to a prior study of an academic office building (U.C. San Francisco Task Force, 2016), the space utilization rate of the subject space was fairly low. At the same time, the wide range of utilization rates raised the question as to why certain open, flexible spaces in the same building showed a higher utilization rate than others. It should be noted that there was a mismatch between the demand and supply of desk types. Especially, the flexible spaces that had individual desks only were utilized less. As individuals used all types of space fairly even, the results can be interpreted as the number of individual desks in the space was more than the quantity demanded. Although it is almost impossible to find one size that fits all, investigating and matching spatial demand and supply based on a corporate's business process, users' work type, and users' preferences are critical to optimizing office spaces. A flexible space, like Areas 1 and 2 in this study, is often utilized for training, meetings, and events. The number of hours for these eventful uses is far fewer than the entire building's operation hours; thus, space uses for all types of activities should be more encouraged.

Spaces providing only shared tables and a combination of shared- and individual-oriented furniture were used more often than the space providing only individual desks, even though all the spaces were open and flexible within the same building. Further analysis of space utilization patterns and activities performed in the space showed the differences in a group versus individual users and the types of activities. The present study's data showed different spatial preferences, depending on the type of activities. The users preferred the space providing different furniture types for teamwork use while users used all spaces evenly for focused work. Interestingly, these shared tables, consisting of high desks and round tables with lounge chairs, were either bar-height or coffee table-height with non-easily movable features requiring relatively great physical effort to move with no caster. However, the desks and chairs in Area 1 and 2, providing individual desks only on the first floor, were easily reconfigurable with casters and locks. These easily movable desks and chairs are often expected to be preferred by group users for effective communication and group members' engagement (Lang et al., 1984; Neil & Etheridge, 2008) but were not used as much in this subject space.

Practitioners and researchers have tried to develop work environments that support diverse workstyles and different activities. This study confirmed that students in a higher education building also selected where they wanted to work according to their activities and reported high environmental satisfaction. When they did group activities or took rests, they chose shared or team furniture configuration. The individual preference for having autonomy in selecting one's work environment based on activities conforms to the previous literature on activity-based offices. The activity-based settings reported higher comfort and environmental satisfaction than those in hive or cell spatial layouts (Candido et al., 2016).

The significance of this study can be summarized in two aspects. First, the study demonstrates mixed methods of understanding space utilization, including self-report, observation, and objective measures. Having subjective and objective measures allows decision-makers to consider different aspects of an office environment as well as find the relationships between factors, which can ultimately inform how office spaces should be designed. Second, the study reassures the importance of investigating users' demand and providing supply that matches the demand in order to avoid oversupply/under-utilization. There is no formula for the supply-demand of spatial arrangement and furniture configuration types or ranges in the field. Also, spatial arrangement types are undefined, non-standardized, and less known. However, they significantly influence users' overall environmental satisfaction, whereas IEQ variables do not associate with user satisfaction with the overall environment as far as they are in the acceptable range. This knowledge gap suggests further investigation specifically focused on spatial arrangements, layouts, and furniture configurations, which can lead to an easy benchmark of guideline tools for similar office or academic settings.

This study poses several limitations regarding internal and external validity. First, there is a gap in data connectivity among different measurements; survey, IEQ measures, and observation. Survey responses were not directly linked to other data sets as the survey distributed on-site in a survey box, letting respondents freely pick up and drop off survey forms in a survey box. Although there was a lack of data connectivity between survey data and other data sets (i.e., observation and environmental measures), the survey items asked the overall perception of the space, not pointing to a specific moment in time when observation or environmental measures were collected. Thus, by the nature of different data collection methods, achieving valid connectivity of the different data sets was difficult. Second, the 15-minute observation interval provided a conservative estimate of the space utilization rate, which indicated the underutilization of the space. Third, ambient environmental measures, such as noise, lighting, temperature, humidity, and carbon dioxide levels, cannot be distinguished from variable furnishings in each space. Lastly, the study has limitations of generalizability due to the nature of a case study.

7. Conclusion

To summarize, users of the subject space were generally satisfied with the ambient environment of the space, although some of the measures were slightly outside of the suggested range. Two sub-divided spaces had much higher space utilization rates than the rest of the space: their average utilization rates were still under 30%. Two main user types, group and individual users, showed different preferences in terms of spatial choices. The selection of space was also associated with the types of activities.

The study suggests a reevaluation of space utilization and programming to increase environmental satisfaction and spatial efficiency. This study provides evidence of the effectiveness of different open space furniture options. Providing furniture matching demand and supply according to users' behavior can enhance space utilization and user satisfaction. Also, an open flexible study space may work differently from the traditional calculation of spatial efficiency in a commercial office space (square feet per full-time employee) or is not designed to have high spatial density. However, a measurable method should be implemented to assess the utilization of the space to reduce operation costs and mitigate buildings' environmental impacts. The methods utilized in this study could be implemented in other buildings to assess space utilization rates and user satisfaction.

Further studies of the Internet of Things hyperconnectivity and sensor devices can provide more accurate data instead of a 15-minute assumption used in this study as well as better data connectivity and integration by tracking individuals' survey responses, time of completion, location of seating, and continuous indoor environmental measurements. For future studies, other possible environmental features, including distance to an entrance, accessibility, interior finishes, and proximity to windows, can be included for a more comprehensive analysis of spatial features. Recruiting more site locations and study participants using mixed methods will benefit future research.

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