COMFORT AT THE EXTREMES 2022

How do occupants perceive thermal comfort in a hybrid office space? A case study of a co-working space in London

Jiayu Pan[1*], Ronita Bardhan[1] and Shushen Chen[1]

[1] Department of Architecture, University of Cambridge, Cambridge CB2 1PX, United Kingdom;

[*] Correspondence author, jp844@cam.ac.uk

Abstract: The work pattern has been reshaped towards a hybrid style since the lockdown in the pandemic, while the office design needs to be evolved with the change in working mode. It is important to understand how to design the workspace to meet the new demand. This study investigates the environmental performance of a flexible co-working space in London by a longitudinal field study, with a specific focus on thermal comfort and lighting sensations and preferences. The field study is composed of a questionnaire survey about occupants' thermal comfort sensations and environmental preferences and a concurrent measurement of indoor environmental data (temperature, relative humidity, air velocity and illumination level). This paper presents a preliminary analysis of the data collected in spring 2022. A total of 79 responses are recorded over three months. The findings in this study are expected to provide new insight into environmental design solutions for the hybrid and flexible work setting.

Keywords: Thermal comfort, Future of work, Office design, Co-working space, Hybrid working

1 Introduction

The indoor environment in offices is important for occupants' health and productivity (Kamarulzaman *et al.*, 2011). As the use of office space has been reshaped significantly from the traditional 9-to-5 style to a hybrid working mode after the pandemic, the office design has evolved towards a more flexible pattern. The new type of office space, like co-working space with a hot-desking system and flexible working hours (Weijs-Perrée *et al.*, 2019), has become a popular alternative option. Therefore, occupants' preferences on office space are altered corresponding to this new change, while the office design evolves with the new demand. There is a rising demand for investigating how environmental design factors could affect the use of offices, especially the hybrid co-working space, in the post-pandemic era.

Based on the hypothesis of people tend to seek the places that are comfortable for them to stay, this study investigates the environmental performance of the flexible working space with a case study of a co-working space in London, with a specific focus on thermal comfort and lighting sensations and preferences. We conduct a standard thermal comfort questionnaire survey and record the indoor environmental parameters around the workspace, such as temperatures, air flow, relative humidity and illuminance level. This field survey follows the standard process of monitoring the in-situ thermal environment while asking the questions. Also, a set of questions about occupants' environmental preferences on seat selection are included in the survey. With the collected set of empirical data from the case study site, this study aims to demonstrate how environmental design factors, such as thermal comfort, ventilation and lighting condition, have affected occupants' seat preferences. This is a preliminary attempt to respond to the significant change brought by the COVID-19 pandemic and deliver more resilient and flexible design strategies for the post-pandemic office space. We expect to suggest corresponding design solutions based on the analysis and findings in a later stage. In this paper, the preliminary results collected in spring 2022 are reported as a demonstration of the potential for future study. This paper is structured as follows: Section 2 reviews the literature on the environmental comfort in office space and the rise of new office design. Section 3 introduces the study site and data collection and analysis methods. Section 4 is the presentation of preliminary results and a discussion of the existing results, and Section 5 gives the conclusion and future research direction.

2 Literature review

The literature review part gives an overview of the background of this study, while it aims to demonstrate the rationale behind the study. The existing studies on two different topics, the environmental comfort in office environment and the transformation of the post-pandemic working environment, are illustrated.

2.1 Environmental comfort in office spaces

Environmental characteristics of offices have been widely studied in the existing literature (Kamarulzaman *et al.*, 2011). Environmental factors like ventilation, thermal comfort, lighting condition and noise level are found to have a significant impact on the occupants' well-being and productivity. This section reviews the impact of environmental design factors on the use and perception of offices.

An office space with good ventilation, high-quality daylight, less noise and comfortable thermal condition is found to have a positive effect on users' overall experience. Ventilation affects the quality of air in the space, while poor air quality leads to concerns about health and poorer productivity (Seppanen, Fisk and Lei, 2005; Aye and Chiazor, 2006; Alker *et al.*, 2015). The presence of daylight is associated with visual comfort, while the use of more natural lighting has an energy-saving potential (Turan *et al.*, 2020). Maximising daylight availability is considered an optimal strategy (Abdollahzadeh, Tahsildoost and Zomorodian, 2020). The noise causes distraction, which undermines the expected efficiency and productivity. The participants in an experimental study report more tiredness and less motivation to work in a noisy environment (Jahncke *et al.*, 2011). A correlation is found between disturbance by noise and dissatisfaction with the environment (Sundstrom *et al.*, 1994). Thermal comfort is determined by temperature, air movement and humidity, while occupants' perceptions depend on their thermal preference, clothing and acceptability (Alker *et al.*, 2015). A high Indoor temperature leads to a reduction in productivity (Kamarulzaman *et al.*, 2011). Studies have observed multiple different types of thermal adaptive approaches in offices, including mechanical adjustments like turning on cooling or heating devices and personal actions like drinking cold drinks and adding clothes (Liu *et al.*, 2012; Liu and Wang, 2019).

A mix of quantitative and qualitative methods is applied to understand the physical environment of office space. Large-scale occupants surveys are effective in collecting the occupants' satisfaction level and subjective well-being sensations on the indoor environmental quality (Huizenga *et al.*, 2006; Newsham *et al.*, 2009; Steemers and Manchanda, 2010). Questionnaire surveys and in-situ environment monitors are commonly used to understand thermal comfort (Kuchen and Fisch, 2009; Akimoto *et al.*, 2010; De Vecchi *et al.*, 2017). Simulation and experiments in laboratory also provide insight into daylight, ventilation and thermal comfort performances (Seppanen, Fisk and Lei, 2005; Tanabe, Nishihara and Haneda, 2007; Turan *et al.*, 2020). However, the existing studies mainly focus on the traditional type of offices, with the feature of fixed send cubicle or open plan structures.

The following section discusses the variations in work styles and office design after the pandemic and demonstrates the research gap in understanding the indoor environment in new types of office.

2.2 The rise of hybrid workspace

The pandemic has reshaped the norm of modern working by implementing the large-scale forced 'work-from-home' experiment. The rise of remote working has enabled the workers with different options of working location. The working mode is gradually shifting towards a hybrid style. In mega-cities like London, though the increase in population brings new jobs and opportunities, the existing office space needs to be revitalised and rebuilt to meet the new demand. The structured office space may no longer be required, while the space could be transformed into a multi-use communal space for work, communication and collaboration (AECOM, 2022). Also, the occupancy rate is expected to decrease as fewer employees would come to offices. This is seen as an opportunity for expenditure saving on rent, maintenance fees and operation costs for business (Boland *et al.*, 2020). Flexible seats and layout can be provided to office occupants as an alternative solution. There is an emerging trend of renovating the existing office spaces with new design standards in the post-pandemic time. For example, a £27 million refurbishment plan has been announced by an office provider in London, including providing alternative spaces in office to work and relax and upgrading the energy efficiency (Neville, 2022). The Microsoft report identifies employees' tendency of prioritising health and well-being over work (Microsoft, 2022). The conceptual model developed by Sorensen *et al.* (2021) emphasizes the importance of workspace and working conditions in ensuring workers' safety, health and well-being. An interview-based study points out organisations' main considerations in designing new offices, including flexibility, functionality, advantage, noise level and sense of community (Nanayakkara, Wilkinson and Ghosh, 2021). In conclusion, in the future of office design, the factors like health and wellbeing, collaboration, resiliency, flexibility and sustainability are expected to be considered more to provide high-quality environment and encourage the use of office (Nanayakkara, Wilkinson and Ghosh, 2021; AECOM, 2022; Ajith *et al.*, 2022).

While working at home leads to the concerns of mental depression, difficulties in concentration and struggles in work-life balance management (Teevan, Hecht and Jaffe, 2021), the local co-working spaces start to become one of the potential solutions when the pandemic restrictions are removed. Employees could get access to the nearby co-working hub without commuting. Compared to the traditional offices with fixed seats and working hours, the occupants have more freedom and flexibility to decide the time they spend working and the location they sit and stay in the co-working space. Several previous studies have demonstrated the understanding of co-working space in research. The co-working space is defined with the concepts of flexibility, change, mobility, community-building and idea-sharing (Fuzi, Clifton and Loudon, 2014; Makaklı, Yücesan and Ozar, 2019). It provides an individual working environment with temporal flexibility, common spaces for events and food facilities (Makaklı, Yücesan and Ozar, 2019). The users choose co-working spaces because they tend to look for a workplace outside their home that enables them to have an inspiring working environment, while the accessibility and atmosphere are two important factors they may consider (Weijs-Perrée *et al.*, 2019). Similar findings are also reported in a later study, with convenient location, open space layout, shared facilities and knowledge sharing as significant factors for user satisfaction (Tan and Lau, 2021).

Therefore, how occupants use and interact with the workspace in this new hybrid norm remains an unknown to be explored, while understanding the driving factors behind occupants' environmental preference could inform the co-working space design in the future. The current understanding of office design is insufficient to deliver better strategies for future and needs to be evolved with the changing pattern of work. This remains a gap in the research area. It is vital to respond to the change and develop design solutions to build a risk-free, healthy and productive working environment for employers and employees. In this study, a case study of a co-working space in London is used as an example to build up understandings on this research gap.

3 Data and Methods

This section introduces the study site and the data collection method. The longitudinal field survey is conducted in a co-working space in London, United Kingdom (UK). A questionnaire survey is designed to understand the subjective thermal comfort and environmental preferences of the occupants in a co-working space while the in-situ measurement of environmental parameters is conducted.

3.1 Study site

London (51° 30′ 26″ N, 0° 7′ 39″ W) is the capital and largest city of the United Kingdom. The city features a humid temperate oceanic variety in Köppen climate classification (Köppen, 1884), with the character of cool to mild winters and warm to hot summers. The monthly variation of weather in London is demonstrated in Figure 3.1 (EnergyPlus, 2022). The monthly average temperature ranges from 5°C (January) to 14 °C (July and August) (Figure 3.1a). The monthly average relative humidity varies from 70% (June) to 88% (December). The average wind speed is around 2 to 4 meters per second (m/s) (Figure 3.1b).

The case study site, the depot_ (18 Wenlock Road, London, N1 7TA), is an experimental creative hybrid co-working space near Old Street. It is found and designed by the lab_ collective and opened in early 2020. The depot_ also functions as an exhibition and event space and a local café. It opens from 9am to 6pm on weekdays. Figure 3.2 shows the plan and indoor environment of the depot_. It occupies the ground floor (Figure 3.2 right) and basement (Figure 3.2 left) of a building. The ground floor is used as a café with a reception and open working space, while the basement area functions as the meeting area with two enclosed meeting rooms and several open flexible meeting spaces. The maximum capacity of the space is around 70. A mixed-mode cooling system with a combination of natural and mechanical ventilation is applied in the space.

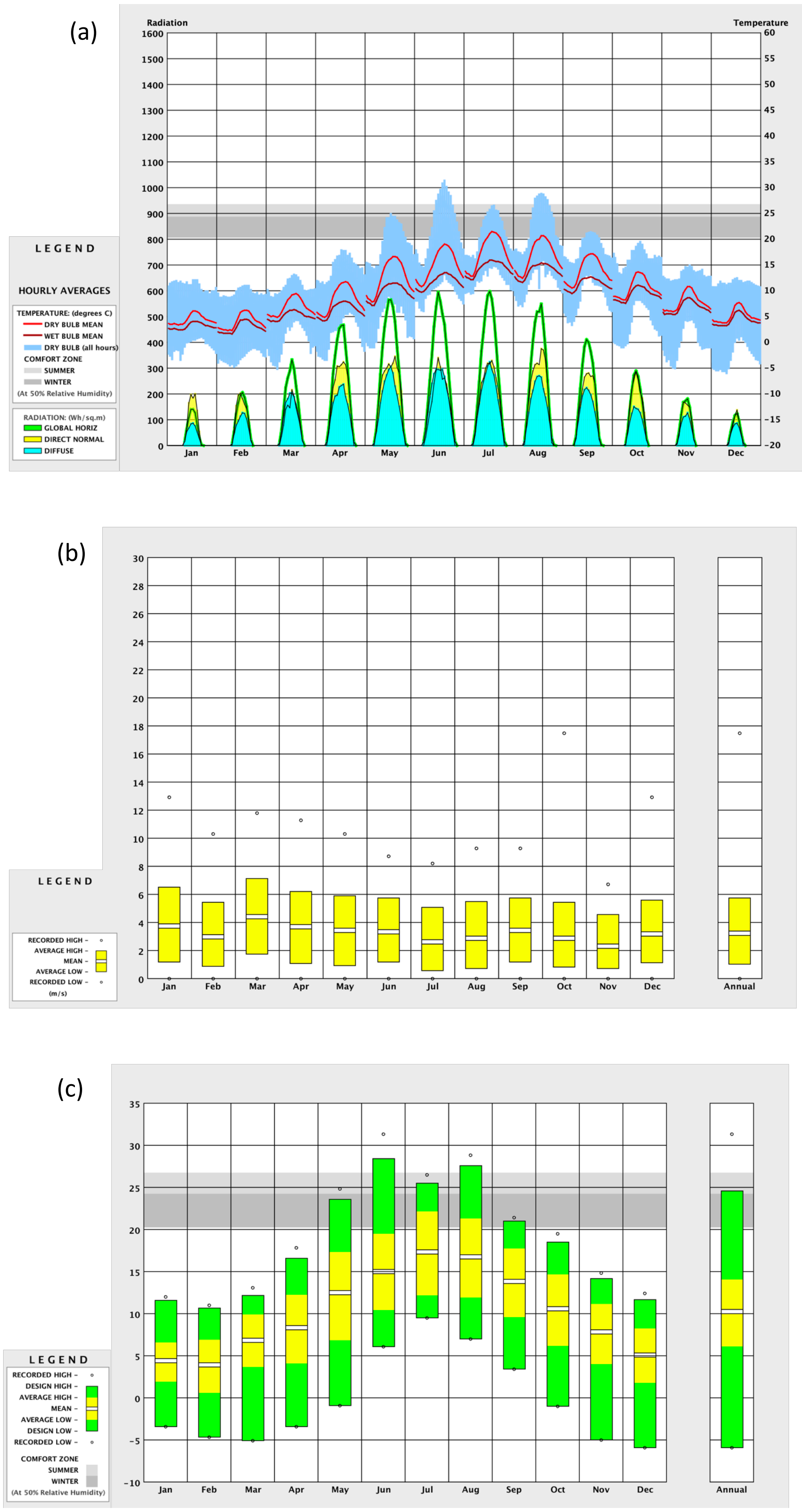

Figure 3.1. Annual weather variation (temperature, humidity (a), windspeed (b) and radiation (c)) in London (EnergyPlus, 2022)

Figure 3.2. Case study, the depot_ (18 Wenlock Road, London N1 7TA): Plan, layout and photos of workspace

3.2 Field study and measurement

A longitudinal field study is conducted to understand the thermal comfort level of occupants, which conforms to the ASHRAE Class II protocol. The data collection is expected to spread over different seasons to capture the diversity in the thermal environment. The standard thermal comfort data collection comprises two parts: the subjective part (thermal comfort sensation questionnaire) and the instrumental part (indoor climate measurement). They are recorded at the same time (Földváry Ličina *et al.*, 2018). This method has been applied in a wide group of thermal comfort studies in various types of environments, such as office spaces in Brazil (De Vecchi *et al.*, 2017), slum rehabilitation housing in India (Malik *et al.*, 2020; Malik and Bardhan, 2021), schools and classrooms in the tropics (Wong and Khoo, 2003; Hamzah *et al.*, 2018) and residential units in Ethiopia (Yadeta *et al.*, 2022). In addition to the standard thermal comfort questions, this study explores the influence of environmental variables on seat preferences with several further questions.

This questionnaire adopted in this study is composed of 3 parts with a total of 20 questions, demographic profiles (age, gender and occupation), subjective comfort votes and environmental variable preferences. The field study is planned to run from March 2022 to March 2023, covering the four seasons in a whole year, in order to capture the variation in thermal sensations. Ethics approval was applied and obtained from the Faculty of Architecture and History of Art Research Ethics Subcommittee at University of Cambridge. According to the ethics requirement, all participants are informed of the project process and contacts. They provide verbal consents to participate in the survey, and they are aware of the right to drop off at any stage. The following subsections introduce the procedure and details of the survey in three parts: the subjective comfort questionnaire, environmental data monitor and the questionnaire on environment and seat preference.

3.2.1 Subjective comfort survey

The understanding of subjective comfort is composed of three parts: demographic information, subjective thermal comfort votes and personal variables. The demographic profile includes gender, age group and occupation of respondents. The collection of subjective thermal information includes thermal sensation votes (TSV), thermal preference votes (TPV), humidity sensation votes (HSV), humidity preference votes (HPV), air movement sensation votes (ASV, air movement preference votes (APV), lighting sensation votes (LSV), daylight preference votes and artificial lighting preference votes. ASHRAE's seven-point scale of thermal sensation and Nicol's five-point scale of preference are applied as listed in Table 3.1 (Humphreys, Nicol and Roaf, 2016). The personal variables include clothing insulation level and activity level. The calculation of clothing insulation level is extracted from ASHRAE standard 55-2010 (ASHRAE, 2013). Respondents' activities in the past 15 minutes are enquired to calculate the corresponding metabolic rates (Engineering ToolBox, 2004a). The indoor environmental controls are not considered due to the limitation of the site. The openings, cooling and heating system are subject to central control, which are not available to occupants.

Table 3.1. Sensation scales (Humphreys et al., 2016)

	Thermal sensation	**Humidity sensation**	**Air movement sensation**	**Lighting sensation**	**Thermal preference**	**Humidity preference**	**Air movement preference**	**Daylight preference**	**Artificial light preference**	**Overall acceptability**
-3	Cold	Very dry	Very still	Too dark						
-2	Cool	Dry	Moderately still	Dark	Much warmer	Much more humid	Much more air movement	Much more daylight	Much more artificial light	
-1	Slightly Cool	Slightly dry	Slightly still	Slightly dark	A bit warmer	A bit more humid	A bit more air movement	A bit more daylight	A bit more artificial light	
0	Neutral	Neither humid nor dry	Neutral	Neutral	No change	No change	No change	No change	No change	Acceptable
+1	Slightly Warm	Slightly humid	Slightly moving	Slightly bright	A bit cooler	A bit drier	A bit less air movement	A bit less daylight	A bit less artificial light	Not acceptable
+2	Warm	humid	Moderately moving	Bright	Much cooler	Much drier	Much less air movement	Much less daylight	Much less artificial light	
+3	Hot	Very humid	Much moving	Too bright						

3.2.2 Field measurement

The outdoor temperature is extracted from the nearest local weather station in London (Met Office, 2022). The indoor climate is monitored by Kestrel 5400 (Kestrel Meters, 2020), which measures air temperature, globe temperature, heat index, relative humidity and air velocity (details about accuracy and range are shown in Table 3.2). The instrument is placed near the participants at about the working plane level while they fill in the questionnaire. The illumination readings are taken at two levels with a URCERI light meter: the working plane/desk level and the human eye level. Each measurement is repeated three times. Figure

3.3 shows an example from the field study which includes the instrumental setup and clothing characteristics.

Table 3.2. Indoor environment measurement (Kestrel Instrument, 2020)

		Range	Resolution	Accuracy
Kestrel 5400	**Air temperature**	-29.0 to 70.0 °C	0.1 °C	0.5 °C
	Globe temperature	-29.0 to 60.0 °C	0.1 °C	1.4 °C
	Heat index	N/A	0.1 °C	4.0°C
	Relative humidity	10 to 90%, 25°C noncondensing	0.1 %RH	2%RH
	Air velocity	0.6 to 40.0 m/s	0.1 m/s	Larger of 3% of reading
Light meter	**Illuminance**	0 lux to 200,000 lux	0.1 lux	N/A

Figure 3.3. Example of measurement and survey

3.2.3 Environment and seat preference survey

In addition to the thermal comfort perception, seat preferences and the importance of environmental variables on seat selection are enquired in the questionnaire survey. The participants are asked whether they are sitting at their preferred seats and requested to point out their preferred seats. They indicate the importance (scale 1 to 5) of a range of environmental and non-environmental factors on their seat preference, such as daylight, artificial light, ventilation, privacy and closeness to people and facilities (listed in Table 3.3). As a validation, the participants also rank their preferences among seven different factors. At last, the respondents rate the whole co-working environment on a scale of 1 to 5 from six different perspectives: ventilation, quietness, thermal comfort, lighting, privacy and overall environmental quality.

Table 3.3. Environmental preference questions

Question type	Factors	Scale
Rate the importance	Good daylight	Scale 1 to 5, 1 as not important, 5 as very important
	Good electric/artificial lighting	
	Good ventilation	
	Thermally comfortable	
	Quieter	
	Near power sockets	
	Close to other people	
	Distant from other people	
	Close to window	
	Nice view	
	Only a few people passing by	
	The closest available seat	
	Close to the cafe/reception	
Ranking the factors	Closeness to window	Rank 1 to 7, 1 as most impactful, 7 as least impactful
	Thermal comfort	
	Lighting	
	Ventilation	
	Privacy	
	Closeness to facilities (e.g. printer, toilet, cafe and reception)	
	Noise level (quietness)	
Rate the environment	Ventilation	Rate 1 to 5, 1 as not satisfied, 5 as very satisfied
	Quietness	
	Thermal Comfort	
	Lighting	
	Privacy	
	Overall	

4 Results and Discussion

This section presents the results and analysis from the preliminary field study conducted in Spring 2022 (March, April and May). The descriptive data are sample sizes and personal variables, followed by the thermal comfort analysis and an analysis of the impact of environmental parameters on seat preferences.

4.1 Descriptive results

4.1.1 Sample size and demographics

A total of 80 participants filled the survey from March to May 2022, with one invalid response. Figure 4.1 illustrates the distribution of the number of participants with respect to time, gender and age group. There are 31, 22 and 26 sets of responses recorded in March, April and

May respectively. The sample size depends significantly on the presence of occupants on the survey day and their availability and willingness to participate. Gender distribution is relatively equal, with around 47% female respondents and 53% male respondents. A majority of participants are in the age group of 18 to 54. The younger population, at the age between 18 to 34, accounts for over 60% of the respondents. There is no significant variation in the participants' age among different months.

Figure 4.2 shows the distribution of occupations. A total of eleven different types of occupations are identified in the questionnaire. A large number of respondents (around 57%) work in the Architecture and Engineering industry, because employees and partners in the lab_ collective use the depot_ as their major in-person workspace and the company mainly works in the built environment industry. There are also a group of participants working in Management (10%), Art and Design (8%) and Sales and Related (5%).

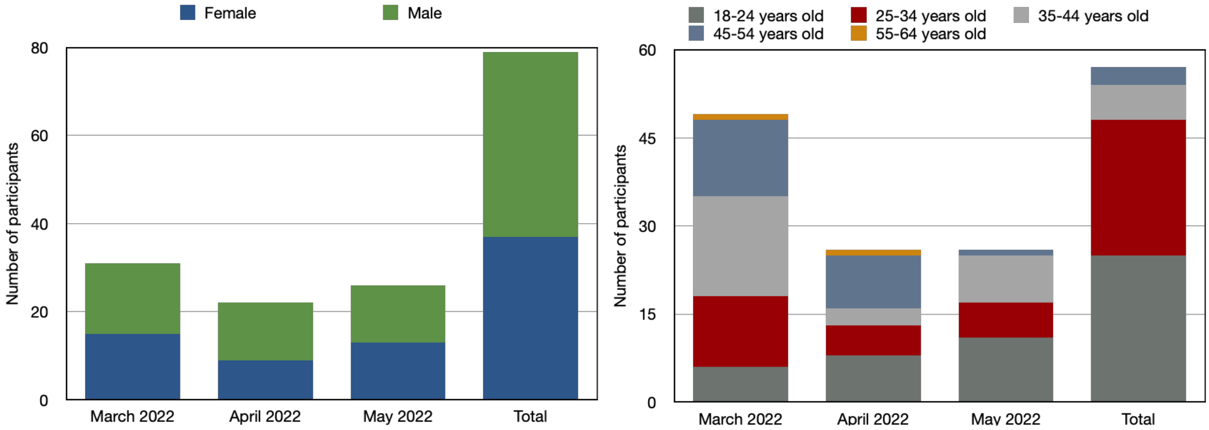

Figure 4.1 Sample size distribution with respect to time, gender and age

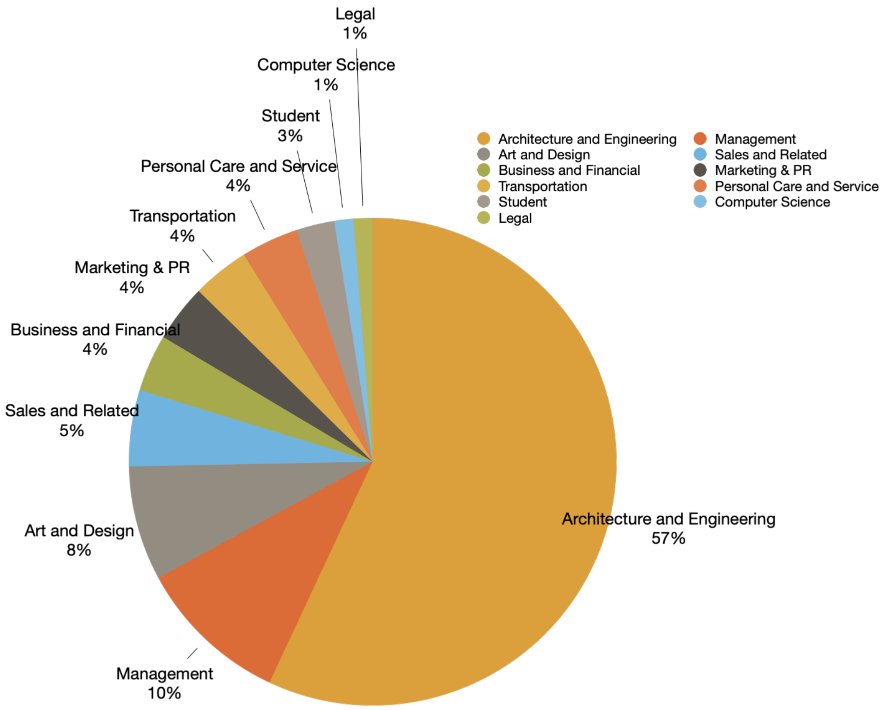

Figure 4.2 Sample distribution with respect to occupations

4.1.2 Personal variables

The personal variables include the clothing insulation and activities over the past 15 minutes. The major clothing combination of occupants is jeans, trousers or skirt as the bottom, shirt, T-shirt or jumper as the top. The mean clothing insulation of all participants is 0.61 clo. The maximum clothing value is 1.09 clo, representing the combination of trousers, long sleeve shirts, jacket, thermal top and socks and shoes. The minimum clothing value is 0.24 clo. The average clothing insulation level decreases from March to May as the weather becomes warmer. Figure 4.3(a) shows the summary of clothing insulation of the participants across different months.

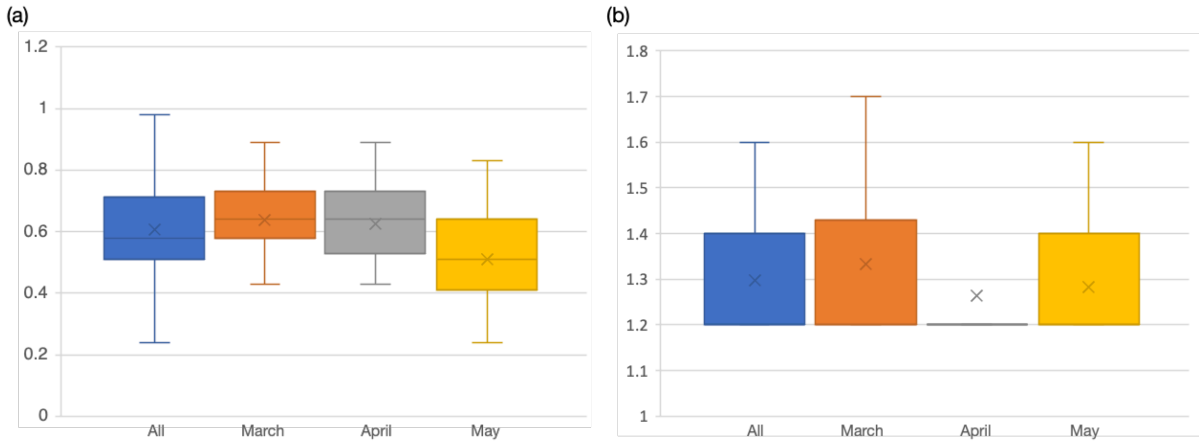

Figure 4.3 (a) Plot of clothing insulation; (b)plot of metabolic rate

Most of the activities reported in the survey are sitting, standing and walking, which corresponds to the typical office activities. Occupants' sedentary activities (1.2 met) include meeting, working and eating and drinking, and their standing activities are mainly standing relaxed (1.2 met) and standing with light and medium activities (1.6 and 2.0 met respectively) (Engineering ToolBox, 2004). The mean metabolic rate is 1.3 met, with a maximum rate of 1.9 and a minimum rate of 1.2 (demonstrated in Figure 4.3(b)). Only six people report they are slightly sweating when answering the questions, while the rest of the respondents indicate 'no sweating'.

4.1.3 Environmental conditions

Outdoor weather conditions on survey days are plotted in Figure 4.4, including the daily variation (from 9am to 6pm) of air temperature, humidity and wind speed. The mean outdoor temperature is around 18.35 °C, and the average humidity and windspeed are 48.11% and 2.1m/s. The highest temperature is recorded at 27°C at 10:00 and 11:00 on the survey day in May, while the lowest temperature is 8.9 °C at 9:00 in April. The temperature in April is relatively low, with relatively higher humidity and air velocity observed. The wind speed in May is 0m/s throughout the whole survey day according to the record.

Indoor climate data is measured by Kestrel 5400 and a light meter. The indoor air temperature varies between 20.1°C and 24.8°C. The average air temperature is around 22.4°C, with a mean of 22.0°C in March, 21.9°C in April and 23.3°C in May. The relative humidity lies in an acceptable range from 38.9% to 50.8%, while the average relative humidity is 44.08%. The illuminance level is measured at the eye level and the desk level separately, with the average illuminance value of 124.06 lux and 170.42 lux respectively. The range of illuminance levels varies significantly for different seats and areas, with a minimum value of 23.1 lux (human level) and 22.9 lux (desk level) and a maximum value of 469.8 lux (eye level) and 668.6 lux (desk level). Normally, the suggested illumination level for office is about 250 to 500 lux at the desk level (Engineering ToolBox, 2004b).

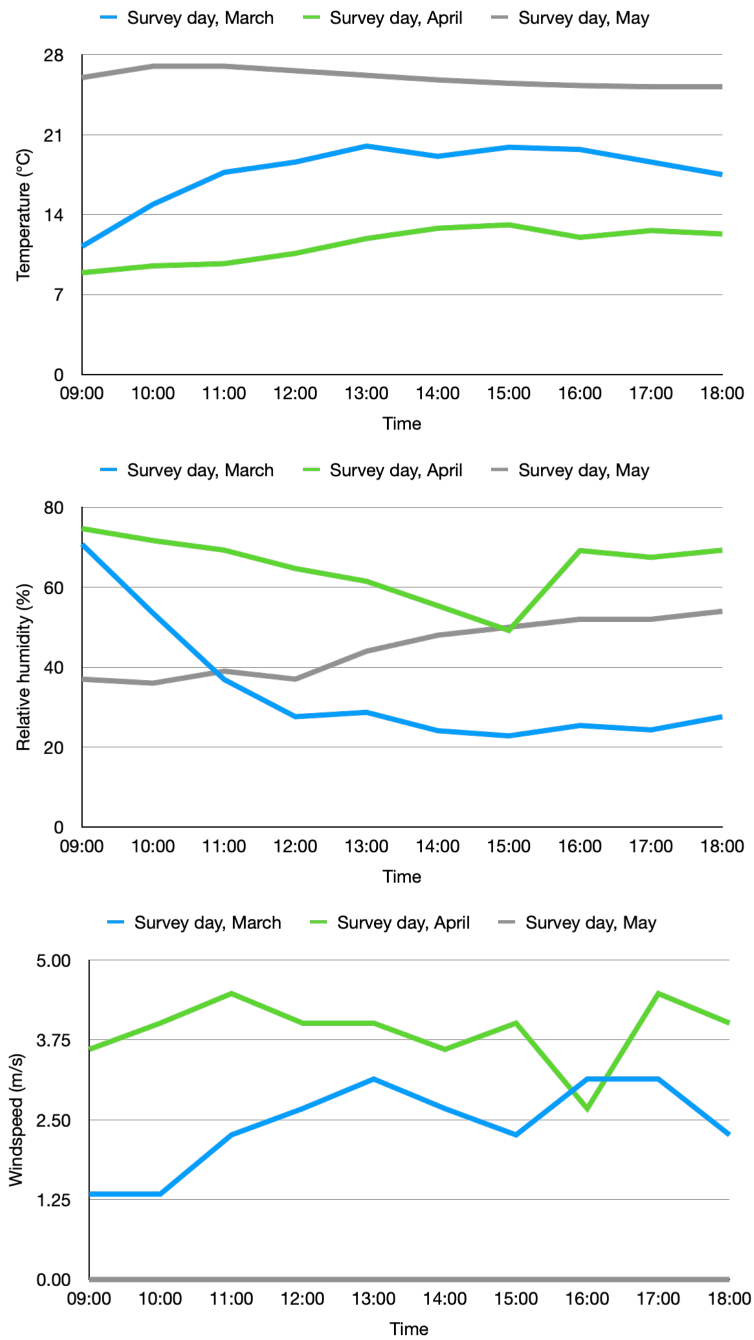

Figure 4.4 Outdoor environment condition extracted from the nearby local weather station (temperature, relative humidity and wind speed)

4.2 Subjective thermal and lighting comfort responses

4.2.1 Thermal sensation and thermal preference votes

The thermal sensation of occupants is measured on a seven-point scale (see Table 3.1), from very cold (-3) to hot (+3). The monthly distribution of TSV is shown in the top chart in Figure 4.5. About 80% of respondents vote within the comfortable range, from slightly cool (-1) to slightly warm (+1), while almost half (47%) of them vote for neutral thermal sensation (0). At the same time, about 14% of participants report for warm sensation (+2), 5% for cool (-2) and 1% for cold (-3) across the three months. The average TSV value is 0.06, which is very close to the neutral sensation. In March and May, the mean TSV values are 0.06 and 0.15 separately, showing a slightly warm sensation. The mean TSV in April is slightly below zero with a value of -0.05, which is on the cool side.

The thermal preference is represented in a five-point scale, from much warmer (-2) to much cooler (+2). A mean TPV value of -0.1 is observed, which indicates a slight tendency toward warmer sensations. The distribution of TPV in each TSV point is shown in Figure 4.5 (b). Around 54% of respondents vote for no change (0), while 29 participants (approximately 37%) select both neutral sensation (0) and a preference for no change (0). Around 28% of people prefer a bit cooler (+1) environment, whereas 18% desire a bit warmer (-1) environment. No one wants a much warmer (-2) or much cooler (+2) environment. The correlation analysis shows the correlation coefficient between TSV and TPV is 0.7, indicating a robust positive association.

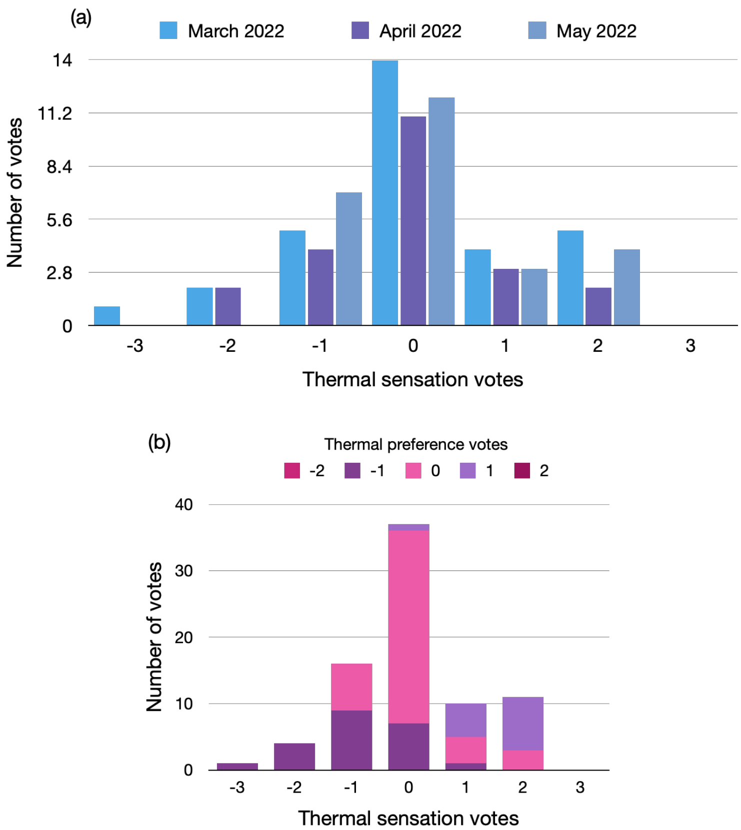

Figure 4.5 (a) Monthly distribution of thermal sensation votes; (b) Cross-tabulation of subjective thermal votes

4.2.2 Humidity and air movement subjective votes

Humidity and air movement sensation and preference are also enquired as they have some impacts on thermal comfort perceptions (Fountain and Arens, 1993; Kitagawa *et al.*, 1999). The monthly distribution of HSV is illustrated in Figure 4.6 (a), and the cross-tabulation of subjective humidity votes is shown in Figure 4.6 (b). All HSV responses lie in the range of dry (-2) to slightly humid (+1), with an average value of -0.19, indicating a relatively neutral sensation but on a slightly dry side. More than 95% of respondents choose within the comfortable humidity range of slightly dry (-1), neutral (0) and slightly humid (+1), while only three occupants feel the environment is dry. The mean HPV value corresponds to the average

HSV with a value of -0.19, which demonstrates a preference for a bit more humid environment but close to no change. A group of 44 people (56%) make neutral selections, with neither humid or dry sensation (0) and no change (0) preference. Four respondents feel slightly dry (-1) but prefer no change (0), while the same amount of people feel slightly humid (+1) but prefer no change (0) too. About 27% of participants desire a bit more humid environment (-1) and 8% prefer a bit drier environment (+1). The correlation between HSV and HPV is positive with a coefficient of 0.7.

Although the instrument fails to detect any wind speed, the sensation of air movement varies among the respondents. The descriptive results of ASV and APV are shown in Figure 4.7. ASV sensations range from very still (-3) to moderately moving (+2). Only 80% of responses are in the range from slightly still (-1) to slightly moving (+1). Seven participants (about 9%) indicate a very still (-3) sensation, and five (6%) choose moderately still (-2). The mean air flow sensation is -0.18, which is close to neutral with a small tendency to still air movement. Meanwhile, the average APV value is -0.44, representing a general preference for more air movement. While 49% of respondents prefer no change (0), there are 47% desire more air movement (-1 or -2). Nine respondents indicate their desire for more air movement even when they sense slight or moderate air movement (1 or 2). The correlation between ASV and APV is positive but not robust with a coefficient of 0.48.

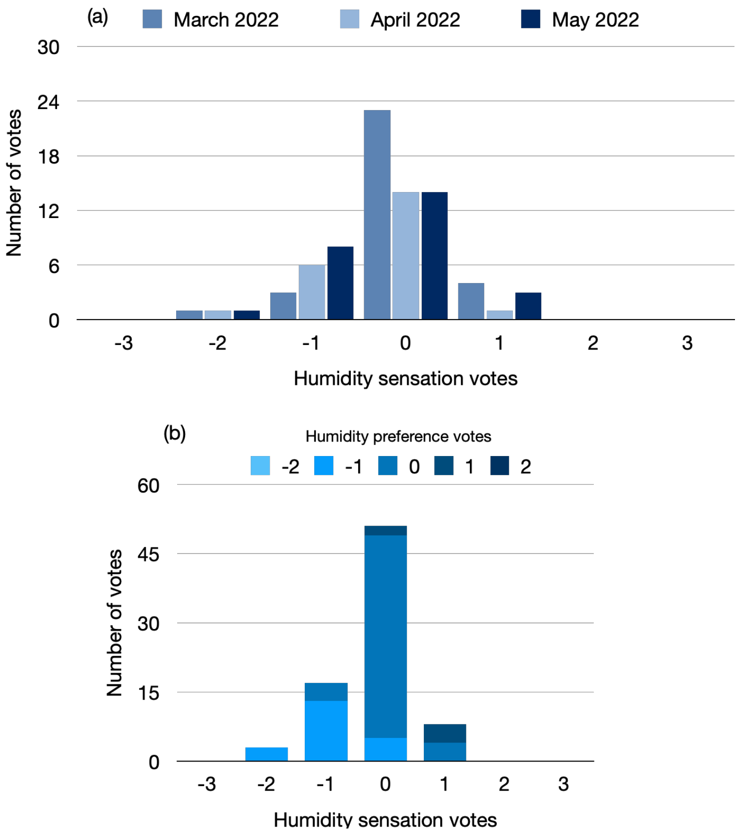

Figure 4.6 (a) Monthly distribution of humidity sensation votes; (b) Cross-tabulation of subjective humidity votes

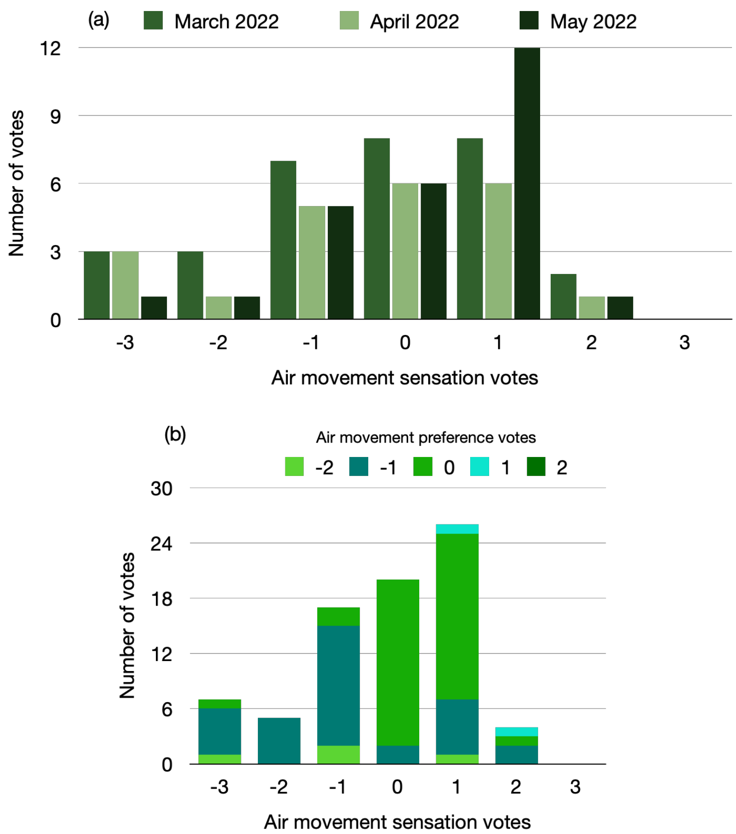

Figure 4.7 (a) Monthly distribution of air movement sensation votes; (b) Cross-tabulation of subjective air movement votes

4.2.3 Lighting sensation and preference votes

The sensation of lighting conditions is also examined in this study, following the same scaling method as above. The lighting preferences are enquired, with two different preference choices regarding daylight and artificial light. Participants can choose their preferences for both. The corresponding results are plotted in Figure 4.8. Around 84% of participants vote within the acceptable range of slightly dark (-1) to slightly bright (+1), with 41% feeling slightly dark (-1), 35% feeling neutral (0) and 8% feeling slightly bright (+1). Five respondents report a dark sensation (-2), while eight suggest a bright sensation (+2). The mean LSV value is -0.25, indicating that the general sensation has a propensity to slightly dark. The average LSV values in March and April are -0.32 and -0.45 respectively, while the mean value in May is neutral (0). Mean LPV shows a preference for a brighter environment, with a value of -0.9 for daylight and -0.27 for artificial light. There are 18% of respondents standing for neutral sensation and no change in daylight and 30% for neutral sensation and no change in artificial light. About 67% of occupants want an environment with more daylight (-1 and -2), while only 22% of occupants prefer an environment with more artificial light. No one votes for less daylight (+1 or +2) while one person wants less artificial light (+1) given her sensation vote of bright (+2). Eleven respondents feel slightly dark (-1) and desiring for much more daylight (-2). Eight respondents choose the slightly bright (+1) or bright (+2) sensations but still prefer more daylight (-1 or -2). Correlation analysis finds a relatively weak positive correlation between LSV and LPVs. The correlation coefficients of LSV and LPVs for daylight and artificial light are both around 0.4.

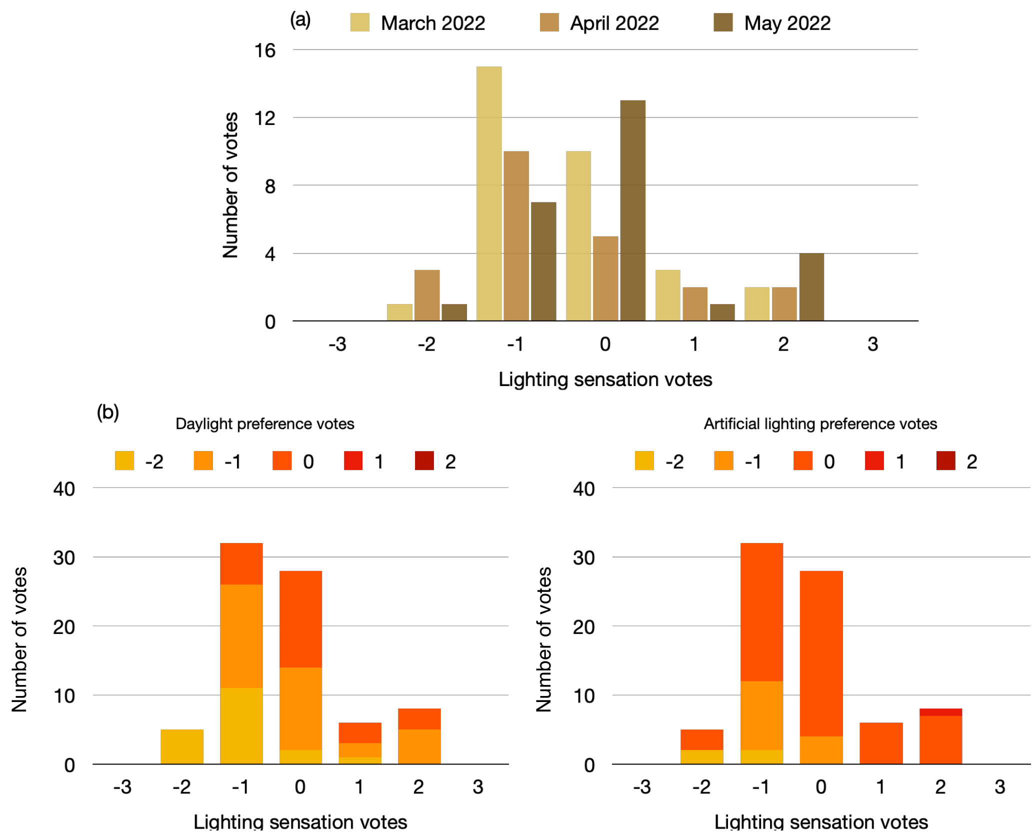

Figure 4.8 (a) Monthly distribution of lighting sensation votes; (b) Cross-tabulation of subjective lighting votes, left: daylight preference votes, right: artificial lighting preference votes

4.2.4 Overall comfort acceptability

The overall comfort acceptability is collected as binary data: acceptable as 0, and unacceptable as 1. Only one person finds the environment not acceptable, while most of the respondents choose 'acceptable'. The results found in this question are also validated by the environment satisfaction rating question (discussed in Section 4.3), while an acceptable average score of 3.68 out of 5 on the environment is given by respondents.

4.3 Seat preference and environmental variables

The participants are enquired about their seat preferences. Most of the respondents (nearly 80%) report that they are sitting at their preferred seats, while only 15 respondents point out their preferred seats are not available. The seats close to a large window, type E in Figure 3.2, are selected as the most popular seat. Figure 4.9 presents the importance of each statement in regard to seat selection. Occupants consider 'good daylight', 'near power sockets' and 'thermally comfortable' as the three most important factors, with the mean importance level of 4.3, 4.2 and 4.0 respectively. The second tier of important factors includes 'close to window', 'good ventilation' and 'nice view', with corresponding average importance rates of 3.92, 3.77 and 3.58. The least important factors are 'closest available seat', 'close to café and reception', 'distant to other people' and 'close to other people' with the importance value under 3. Participants also rank their preference among seven different factors (results shown in Figure 4.10). The ranking results reveal the importance of the factors like closeness to window, lighting condition and thermal comfort when occupants decide where to sit. The participants may give less consideration to closeness to facilities and privacy in their seat preference.

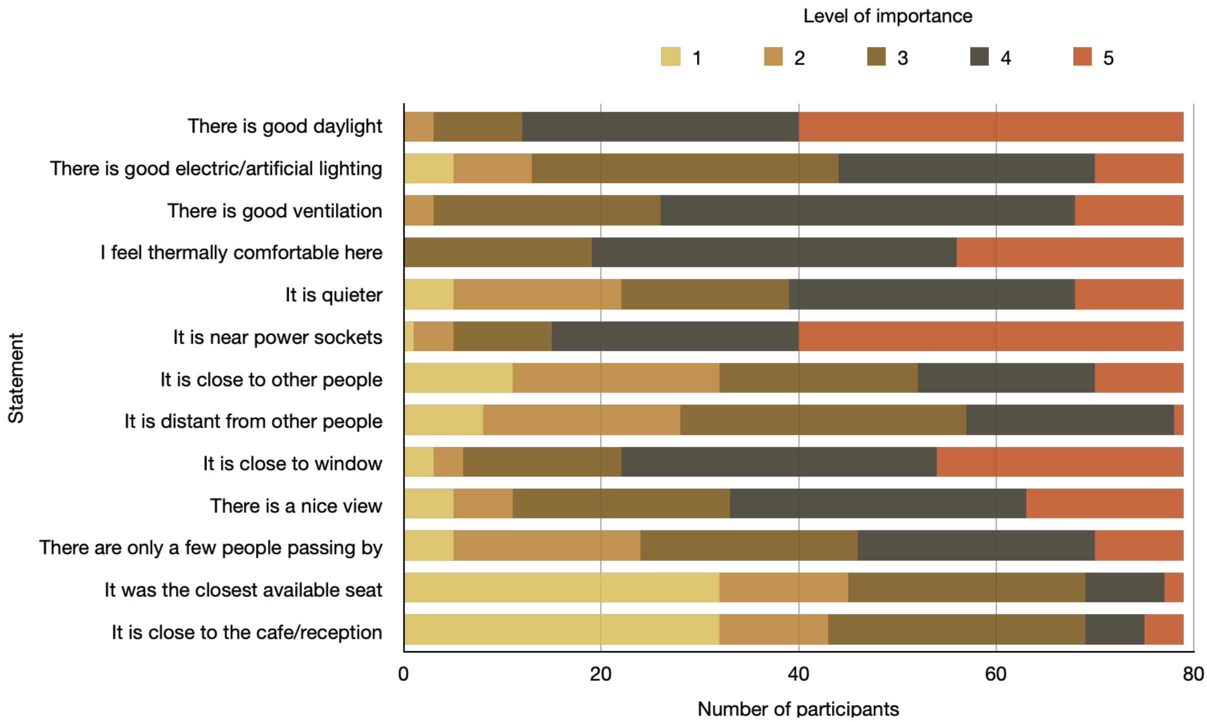

Figure 4.9 Level of importance of each statement in regard to seat selection

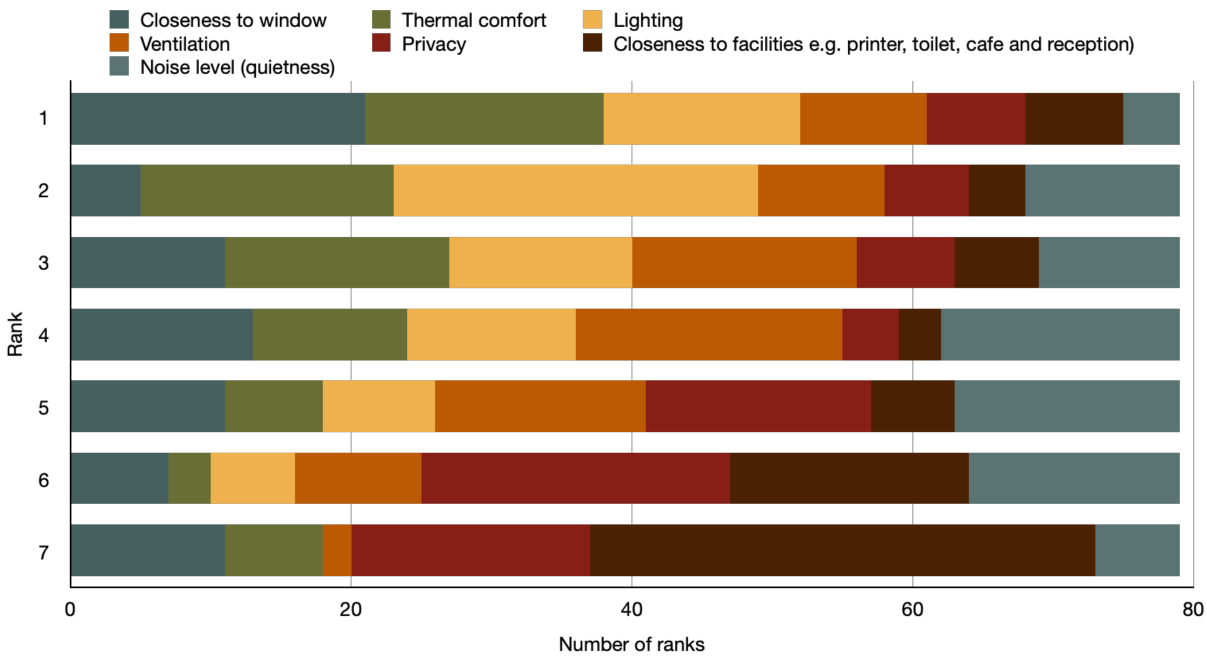

Figure 4.10 Ranking results among seven design factors

At the end of this questionnaire, participants rate this co-working space based on their satisfaction with five different environmental parameters and one overall score (see Figure 4.11). Ventilation, lighting and thermal comfort receive higher scores compared to privacy and quietness. The average overall score is around 3.68, which is an acceptable level of satisfaction.

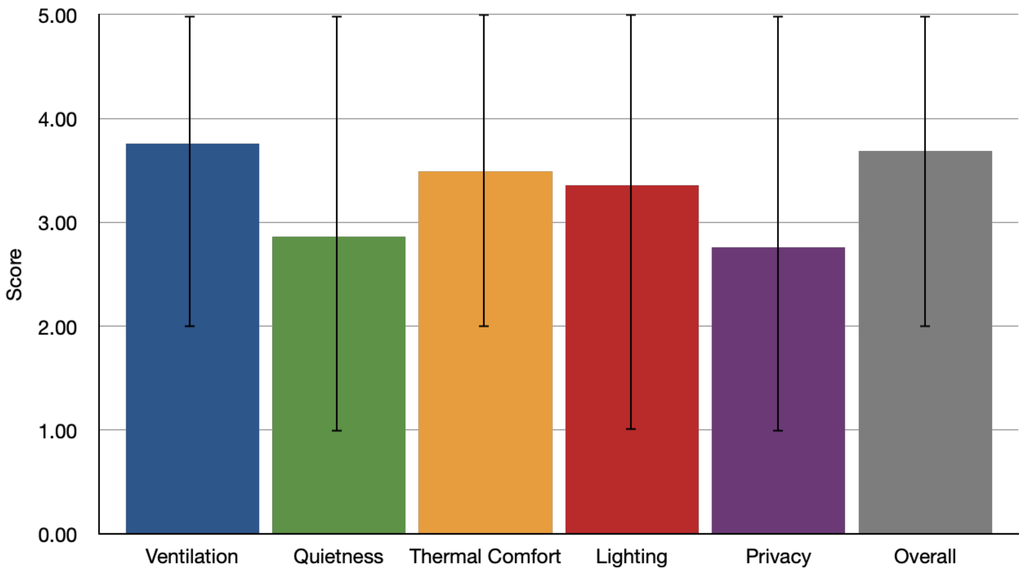

Figure 4.11 Overall evaluation of the environment

4.4 Discussion

The preliminary results with 80 participants from the field study in a co-working space conducted in Spring 2022 confirm the impact of environmental design factors on seat preference. Two major findings are summarised as follows:

- Firstly, thermal comfort sensation is generally acceptable in the space, with a slight overall tendency on warm, dry and still movement sensation. At the same time, the occupants tend to adjust to a neutral thermal comfort and humidity situation by indicating a preference for a slightly cooler and a bit more humid environment. Also, thermal comfort is considered an important factor to the occupants when choosing their seats.
- Secondly, a strong preference for more daylight and more air movement is observed in the survey results, regardless of participants' actual sensations. Daylight and ventilation are also two factors favoured by the occupants. They suggest they would consider the daylight and closeness to window as two key factors regarding seat preferences. This argument is double-validated by their actual choice of seat and selection of preferred seat – the table near the large window (type E) is the most popular place. This finding corresponds to the former research on office physical environment, that more daylight and ventilation and outside window are preferred and lead to higher satisfaction (Newsham *et al.*, 2009; Alker *et al.*, 2015).
- Overall, this co-working environment is generally acceptable for occupants. Although its performance of privacy level and noise is relatively unsatisfying, most of the occupants are satisfied with this working environment.

5 Conclusion

The indoor physical environment in offices plays an important role in promoting users' perception, health and well-being (Kamarulzaman *et al.*, 2011), at the same time, providing a high-quality environment by natural design strategies can contribute to building operational energy saving (Steemers and Manchanda, 2010). While the type and design of modern offices are expected to be transformed significantly in the post-pandemic time, a gap of lack of understanding of effective design for new office types is identified. This investigation intends to fill this gap by conducting a longitudinal field survey on thermal comfort analysis and environmental perceptions and preferences of the occupants.

In this preliminary analysis, the thermal comfort level in the case study office space Spring 2022 is demonstrated with a field survey in a co-working space in London. Generally, the results have reflected a generally acceptable situation regarding thermal and lighting comfort, and they consider the factors like thermal comfort, daylight and closeness to window important to them when deciding where to sit. More daylight and air movement are desirable options for many occupants.

In conclusion, this study captures the thermal experience and environmental preference in a co-working flexible office using a questionnaire survey and in-situ measurements. The number of participants presented in this writing is relatively small, while more data is expected to be collected over the following year and more findings would be revealed as the survey responses accumulate. Further investigation is going to be developed along with the calculation of radiant temperature and operative temperature and simulation methods to predict thermal comfort level in the space. The analysis and results are expected to provide an insight into how to design for a better environment in the future workspace.

6 Reference

Abdollahzadeh, N., Tahsildoost, M. and Zomorodian, Z. S. (2020) 'A method of partition design for open-plan offices based on daylight performance evaluation', *Journal of Building Engineering*. Elsevier Ltd, 29(July 2019), p. 101171. doi: 10.1016/j.jobe.2020.101171.

AECOM (2022) *The future of London's offices*, *Commercial & Residential*. Available at: https://aecom.com/without-limits/publication/future-londons-offices/ (Accessed: 29 May 2022).

Ajith, M. *et al.* (2022) 'Sustainable technology, materials and working layout for post covid-19 office spaces', pp. 1–6. doi: 10.1109/aset53988.2022.9734927.

Akimoto, T. *et al.* (2010) 'Thermal comfort and productivity - Evaluation of workplace environment in a task conditioned office', *Building and Environment*. Elsevier Ltd, 45(1), pp. 45–50. doi: 10.1016/j.buildenv.2009.06.022.

Alker, J. *et al.* (2015) *Productivity in Offices - the next chapter for green building*, *World Green building Council*.

ASHRAE (2013) 'Thermal Environmental Conditions for Human Occupancy', *ANSI/ASHRAE Addendum h to ANSI/ASHRAE Standard 55-2010*. Available at: www.ashrae.org.

Aye, L. and Chiazor, M. (2006) 'Evaluation of occupant perception and satisfaction in two new office buildings', *Solar 2005, Renewable Energy for a Sustainable Future - A challenge for a post carbon world, Proceedings of the 43rd Annual conference of Australian and New Zealand Solar Energy Society*, (November 2005).

Boland, B. *et al.* (2020) 'Reimagining the office and work life after COVID-19', *McKinsey & Company*, (June), pp. 1–5.

EnergyPlus (2022) *Weather Data*, *EnergyPlus*. Available at: https://energyplus.net/weather (Accessed: 27 May 2022).

Engineering ToolBox (2004a) *Met - Metabolic Rate*. [online] Available at: https://www.engineeringtoolbox.com/met-metabolic-rate-d_733.html

Engineering ToolBox (2004b) *Illuminance - Recommended Light Level*. [online] Available at: https://www.engineeringtoolbox.com/light-level-rooms-d_708.html.

Földváry Ličina, V. *et al.* (2018) 'Development of the ASHRAE Global Thermal Comfort Database II', *Building and Environment*, 142, pp. 502–512. doi: 10.1016/j.buildenv.2018.06.022.

Fountain, M. E. and Arens, E. A. (1993) 'Air movement and thermal comfort', *ASHRAE Journal*, 35(8).

Fuzi, A., Clifton, N. and Loudon, G. (2014) 'New in-house organizational spaces that support creativity and innovation: the co-working space', *R & D Management Conference*, pp. 3–6. Available at: https://repository.cardiffmet.ac.uk/dspace/bitstream/10369/7725/2/AF-NC-GL R%26D Mgmt final.pdf.

Hamzah, B. *et al.* (2018) 'Thermal comfort analyses of secondary school students in the tropics', *Buildings*, 8(4), pp. 1–19. doi: 10.3390/buildings8040056.

Huizenga, C. *et al.* (2006) 'Air quality and thermal comfort in office buildings: Results of a large indoor environmental quality survey', *HB 2006 - Healthy Buildings: Creating a Healthy Indoor Environment for People, Proceedings*, 3, pp. 393–397.

Humphreys, M., Nicol, F. and Roaf, S. (2016) *Adaptive Thermal Comfort: Foundations and Analysis*. Routledge.

Kamarulzaman, N. *et al.* (2011) 'An overview of the influence of physical office environments towards employees', *Procedia Engineering*, 20, pp. 262–268. doi: 10.1016/j.proeng.2011.11.164.

Kestrel Meters (2020) *Kestrel 5400 Heat Stress Trackers Certificate of Conformity*, *KestrelMeters.com*. Available at: https://kestrelinstruments.com/mwdownloads/download/link/id/41/ (Accessed: 25 May 2022).

Kitagawa, K. *et al.* (1999) 'Effect of humidity and small air movement on thermal comfort under a radiant cooling ceiling by subjective experiments', *Energy and Buildings*, 30(2), pp. 185–193. doi: 10.1016/S0378-7788(98)00086-3.

Köppen, W. (1884) 'Die Wärmezonen der Erde, nach der Dauer der heissen, gemässigten und kalten Zeit und nach der Wirkung der Wärme auf die organische Welt betrachtet (The thermal zones of the Earth according to the duration of hot, moderate and cold periods and of the impac', *Meteorol. Z.*, 1, pp. 214–226.

Kuchen, E. and Fisch, M. N. (2009) 'Spot Monitoring: Thermal comfort evaluation in 25 office buildings in winter', *Building and Environment*. Elsevier Ltd, 44(4), pp. 839–847. doi: 10.1016/j.buildenv.2008.06.023.

Liu, J. *et al.* (2012) 'Occupants' behavioural adaptation in workplaces with non-central heating and cooling systems', *Applied Thermal Engineering*. Elsevier Ltd, 35(1), pp. 40–54. doi: 10.1016/j.applthermaleng.2011.09.037.

Liu, J. and Wang, J. (2019) 'Thermal comfort and thermal adaptive behaviours in office buildings: A case study in Chongqing, China', *IOP Conference Series: Earth and Environmental Science*, 371(2). doi: 10.1088/1755-1315/371/2/022002.

Makaklı, E. S., Yücesan, E. and Ozar, B. (2019) 'Co-Working Space Concept in the Spatial and Urban Context: A Case Study of 'Kolektif House', *FSM Scholarly Studies:Journal of Humanities and Social Sciences*, (14), pp. 297–312. Available at: https://dergipark.org.tr/en/download/article-file/908663.

Malik, J. *et al.* (2020) 'Contextualising adaptive comfort behaviour within low-income housing of Mumbai, India', *Building and Environment*. Elsevier Ltd, 177(January), p. 106877. doi: 10.1016/j.buildenv.2020.106877.

Malik, J. and Bardhan, R. (2021) 'Thermal comfort perception in naturally ventilated affordable housing of India', *Advances in Building Energy Research*, 0(0), pp. 1–29. doi: 10.1080/17512549.2021.1907224.

Met Office (2022) *Weather Observations Website*. Available at: https://wow.metoffice.gov.uk/ (Accessed: 26 May 2022).

Microsoft (2022) 'Great Expectations: Making Hybrid Work Work', *2022 Work Trend Index: Annual Report Great*, pp. 1–56. Available at: https://www.microsoft.com/en-us/worklab/work-trend-index/great-expectations-making-hybrid-work-work.

Nanayakkara, K. T., Wilkinson, S. J. and Ghosh, S. (2021) 'Future office layouts for large organisations: workplace specialist and design firms' perspective', *Journal of Corporate Real Estate*, 23(2), pp. 69–86. doi: 10.1108/JCRE-02-2020-0012.

Neville, M. (2022) '£27m "future of work" London office refurbishment project enlists Grand Designs leadership', *BDaily News*, 13 April. Available at: https://bdaily.co.uk/articles/2022/04/13/27m-future-of-work-london-office-refurbishment-project-enlists-grand-designs-leadership (Accessed: 20 April 2022).

Newsham, G. *et al.* (2009) 'Linking indoor environment conditions to job satisfaction: A field study', *Building Research and Information*, 37(2), pp. 129–147. doi: 10.1080/09613210802710298.

Seppanen, O., Fisk, W. J. and Lei, Q. H. (2005) 'Ventilation and Work Performance in Office Work'. Available at: https://escholarship.org/uc/item/2374990t.

Sorensen, G. *et al.* (2021) 'The future of research on work, safety, health and wellbeing: A guiding conceptual framework', *Social Science and Medicine*. Elsevier Ltd, 269, p. 113593. doi: 10.1016/j.socscimed.2020.113593.

Steemers, K. and Manchanda, S. (2010) 'Energy efficient design and occupant well-being: Case studies in the UK and India', *Building and Environment*. Elsevier Ltd, 45(2), pp. 270–278. doi: 10.1016/j.buildenv.2009.08.025.

Tan, T. H. and Lau, K. (2021) 'Understanding users' and hosts' motives to co-working space: Case of Kuala Lumpur, Malaysia', *Open House International*, 46(1), pp. 81–95. doi: 10.1108/ohi-07-2020-0077.

Tanabe, S. I., Nishihara, N. and Haneda, M. (2007) 'Indoor temperature, productivity, and fatigue in office tasks', *HVAC and R Research*, 13(4), pp. 623–633. doi: 10.1080/10789669.2007.10390975.

Teevan, J., Hecht, B. and Jaffe, S. (2021) *The New Future of Work: Research from Microsoft into the Pandemic's Impact on Work Practices*, *Microsoft*. Available at: https://aka.ms/newfutureofwork.%0AOr.

Turan, I. *et al.* (2020) 'The value of daylight in office spaces', *Building and Environment*. Elsevier Ltd, 168(October 2019), p. 106503. doi: 10.1016/j.buildenv.2019.106503.

De Vecchi, R. *et al.* (2017) 'Thermal comfort in office buildings: Findings from a field study in mixed-mode and fully-air conditioning environments under humid subtropical conditions', *Building and Environment*. Elsevier Ltd, 123, pp. 672–683. doi: 10.1016/j.buildenv.2017.07.029.

Weijs-Perrée, M. *et al.* (2019) 'Analysing user preferences for co-working space characteristics', *Building Research and Information*. Taylor & Francis, 47(5), pp. 534–548. doi: 10.1080/09613218.2018.1463750.

Wong, N. H. and Khoo, S. S. (2003) 'Thermal comfort in classrooms in the tropics', *Energy and Buildings*, 35(4), pp. 337–351. doi: 10.1016/S0378-7788(02)00109-3.

Yadeta, C. *et al.* (2022) 'An Investigation of Human Thermal Comfort and Adaptation in Naturally Ventilated Residential Buildings and its implication for energy use in tropical climates of Ethiopia', *Science and Technology for the Built Environment*. Taylor & Francis, 0(0), pp. 1–29. doi: 10.1080/23744731.2022.2048574.