UCL
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Investigating the influence of cultural background on daylight perception

Gizem Izmir Tunahan

ORCID: 0000-0003-1473-9351

A thesis submitted in partial fulfilment of the requirements of
the University College London for the degree of Doctor of Philosophy

Bartlett School of Environment, Energy and Resources,
University College London

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Declaration

I confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Gizem Izmir Tunahan

Date: 31.08.2022

Abstract

Millions of people migrate every year, aiming to settle either permanently or temporarily in new places. People from countries with different intensities of daylight might have various perceptions and expectations towards the climatic and indoor conditions. It might result from a previously accustomed lighting environment and other associated factors, namely individual cultural background. It is important because study outcomes may be utilised by architects and lighting professionals on how to design buildings and interior spaces depending on occupants’ perceptions and expectations to increase occupants’ satisfaction. This knowledge also can be used to save energy because the efficient use of daylight can reduce the energy consumption of both HVAC and illumination systems.

To date, few studies have explored the relationship between cultural background and daylight perception; however, they mostly focused on glare sensitivity rather than daylight intensity. Cross-cultural studies aiming to investigate lighting preferences in interior environments are also rare. What is not yet known is the importance of cultural background and its impact on daylight perception, expectation, and satisfaction. Therefore, the development of a methodology for assessing daylight perception and its application in the context of cultural background are the main objectives of this research project, in order to investigate the impact of cultural background on daylight perception.

In this thesis, three subjective evaluation methods were used to assess participants' daylight perceptions: subjective ratings, seat preference, and daylight boundary line drawings, and the perceived daylight availability obtained through these methods were compared to measured daylight availability. It was demonstrated that perceived daylight availability obtained through seat preference and subjective statement methods corresponds to some extent with actual daylight availability ($p<0.01$ and $p =0.002$, respectively). The findings obtained from both students’ seat selections and occupancy data from motion sensors in the library also highlighted the importance of daylight availability in the seat selection of students in the libraries. However, the lit area drawn by participants representing the perceived daylight conditions as part of the daylight boundary line method varied extensively

from person to person regardless of actual daylight measurements. In other respects, a systematic review was conducted to create a conceptual framework of cultural background in the lit environment, and factors thought to be influencing daylight perception in the cultural context had been defined in four ways. These were ethnicity and/or physiological properties of individual eyes, the residential area, the previous luminance environment and sociocultural background.

Finally, the developed methodology based on the previous findings was applied to understand if individuals perceive daylight conditions differently due to their cultural backgrounds. Although some findings proved that culture might be an important factor in daylight perception, the study results did not provide strong evidence of a cultural background influence on daylight perception. However, the number of participants in this study (N=193) was limited, and this unique topic requires additional research with larger sample size.

Impact statement

This study aims to understand whether individuals perceive daylight conditions differently from each other due to their cultural backgrounds by developing a methodology to assess individuals' daylight perception and its application in the context of cultural background. The most significant contribution of this research is to provide a better understanding of the factors that could play a role in the daylight perception of participants. Increasing the knowledge of individuals' perceptions will help us provide lighting conditions that meet their needs and expectations, making them more satisfied with the indoor conditions in the built environment.

Prior studies relevant to many aspects were limited in this thesis. For these reasons, this study required the development of several methodologies, assessment methods and theoretical backgrounds to fill the literature gaps. The findings from this unique topic with the developed methodology and assessment methods could be applied to other studies to investigate the influence of several factors on daylight perception and also seat selection.

Daylighting standards are developed primarily with visual task requirements but with a limited scientific understanding of the role of cultural background in occupants' daylight perceptions and preferences. Namely, recommended standards for illumination levels in libraries do not represent the differences in daylight perception of individuals from different cultural backgrounds. Therefore, the findings of this thesis, or future research derived from these findings, could be applied to daylighting design guidelines.

The insights gained in this research have potentially important implications for daylighting design of library buildings as well as for understanding the relationship between daylighting and human behaviour. Therefore, it can support architects and lighting professionals working in the design of library buildings. The results can help designers consider not only the shape of the building but also seating spaces providing different characteristics of space for students during the design stage.

Last but not least, this thesis may help to avoid unnecessary energy consumption in the built environment. Knowing the variation in occupants' daylight perceptions due to their cultural background could also help save consumed energy by providing unique lighting conditions that meet those needs and preferences instead of typical or average needs. The total energy consumption of a library could also be reduced considering the occupancy status of the library. In this way, the opening hours could be rearranged depending on the hours when a room is primarily vacant or occupied by a few people.

Covid 19 impact statement

This research project aimed to investigate the influence of cultural background on the subjective assessment of daylight. Each chapter has its own methodology and research activities planned to answer the research questions and develop a proper method to investigate the relationship between cultural background and daylight perception.

The study conducted at the Bartlett Library with 193 students to assess the methodology and preliminary findings was successfully completed and reported in the thesis. The following research activity was planned to expand the previous study to all UCL libraries to reach the highest number of students from various cultural backgrounds. However, planned research activities were disrupted due to Covid-19 inability to undertake fieldwork due to lack of and reduced access to UCL libraries. Although a few libraries were reopened later, specific seat places were restricted to maintain social distancing, considerably impacting the study's findings while limiting the available seat selections. Also, the number of students preferring to study in the libraries was much lower than usual.

In the thesis, Chapter 6 aimed to investigate how students' cultural backgrounds influence their perception of daylight by combining the findings obtained from previous chapters. The goal of this chapter was to conduct two consecutive studies with different sample sizes. The first research project proposed for Chapter 6 was carried out at the Bartlett Library with 193 students to evaluate preliminary findings and the developed methodology, and it was successfully completed and reported in the thesis. The following research activity was planned to extend the previous study to all UCL libraries to reach as many students from diverse cultural backgrounds as possible. However, planned research activities were disrupted due to Covid-19 inability to undertake fieldwork due to lack of and reduced access to UCL libraries. Although a few libraries were later reopened, specific seat places were restricted to maintain social distance, significantly influencing the study's findings while limiting available seat options. In addition, the number of students preferring to study in libraries was significantly lower than usual. This research project would have reached a much larger number of students and produced statistically more accurate results if COVID-19 restrictions had not interfered with the stated research activities.

Acknowledgements

I would first like to thank my research guide, Hector Altamirano, whose zeal for perfection and conviction has always inspired me to do more. Under his guidance, I successfully overcame many difficulties and learned a lot. Also, I greatly appreciate and acknowledge the support received from Jemima Unwin and Cosmin Ticleanu. Most of the results described in this thesis would not have been obtained without their support.

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I acknowledge the people who mean a lot to me, my parents, Berrin Izmir and Levent Izmir, for showing faith in me and giving me the liberty to choose what I desire. I salute you all for the selfless love, care, pain and sacrifice you made to shape my life. I would never be able to pay back the love and affection showered upon me by my parents. Also, I express my thanks to my little brother Kerem Mert Izmir for his support and valuable prayers.

I would like to express my great appreciation to the Republic of Turkey Ministry of National Education for supporting and sponsoring my education process.

UCL Research paper declaration forms

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Terms and definitions

Term	Definition
daylight	the visible part of global solar radiation [1]
daylight provision	level of illuminance achieved across a fraction of a reference plane for a fraction of daylight hours within a space [1]
discomfort glare	the glare that causes discomfort without necessarily impairing the vision of objects [1]
glare	condition of vision in which there is discomfort or a reduction in the ability to see details or objects is caused by an unsuitable distribution or range of luminance or extreme contrasts [1]
illuminance	the amount of light that reaches a point on a given plane in an interior or the light flow strikes a unit surface area of one square metre. The standard unit for illuminance is Lux (lx) which is lumens per square meter (lm/m2) [1]
luminance	the amount of light reflected from a surface in a given direction. The standard unit for luminance is candela per square meter (cd/m2) [1]
work plane	the level at which work is done and at which illuminance is specified and measured. This is typically a horizontal plane located at desk height [1]
inter-individual differences	Differences that are observed between people
intra-individual differences	Differences that are observed within the same person when they are assessed at different times or in different situations

CHAPTER 1: Introduction

1.1. Background

The characteristics of an indoor lighting environment could significantly affect the comfort, well-being and productivity of building occupants [2]. The lighting quality assessment typically includes photometric measurements, which do not provide a complete representation of an environment's lighting quality [3]. The assessment should not only consider the links between the lighting levels and the characteristics of the space where light is measured but, more importantly, how people perceive that environment. As of today, far too little attention has been paid to daylight perception and its evaluation methods, as highlighted by the Commission Internationale de l'Eclairage 2013 and the International Energy Agency [4]. Understanding its complexity and potential benefits could be crucial, especially in the context of health and wellbeing, mood, and also cognitive and academic performance. Up to now, several studies have shown that exposure to different amounts and characteristics of daylight could enhance students' cognitive performance [5] [6]. However, it is still not known how students' daylight perceptions and preferences and the level of daylight they are satisfied with will contribute to their academic performance.

In recent years, there has been a growing trend towards international migration, mainly for permanent or temporary settlements, reaching up to 281 million in 2020 [7], namely one in thirty people in the world, and it is expected to be around 405 million by 2050 [8]. People migrate to other countries due to usually specific push and pull factors. Push factors are the reasons people leave a country, such as few jobs, war, natural diseases and famine. Pull factors are why they move to a particular country, such as better job opportunities, education, healthcare, or safety [9]. Although the reasons for international migration mainly depend on the host and home country's socio-political, demographic, economic and environmental circumstances, the US, Saudi Arabia, Germany, Russia and the UK are the most popular destinations respectively for migrants, and almost half of the migrant population in the world emigrates from China for various purposes [8].

The UK, one of the top destinations for international migrants, has shown a significant increase in immigration by 91%, from 329,000 in 1991 to 625,000 in 2018 (The COVID-19 pandemic has had a significant impact on the UK immigration system since 2019, both in terms of restricting migrant movements to and from the UK. Therefore, 2018 migration statistic data were reported). June 2018 migration statistic data showed that working is the most common reason for immigration to the UK (39%), followed by studying (32%) and accompanying a relative (13%) [10]. Studying abroad is one of the main reasons for temporary migration; an excellent way to gain new perspectives, develop a global network and find more career opportunities. In addition to individual contributions to the personal development of the students, student immigration also has a considerable economic benefit to the host country. The economic value of international students to the UK is £13.6 billion annually, with fees, accommodation and off-campus spending as the fifth largest export earnings [11] as, equivalent to the salary of 31,700 nurses or 25,000 police officers and £310 annual extra funding per UK residents [12]. London is the leading city in the UK, welcoming approximately 100,000 international students annually [13], namely a third of the total student immigrants in the UK [14], with £2.74 billion in education export earnings [15].

In the UK, student migrants constitute 19% of higher education (equals to 438,010 students) with 13.6% of undergraduate, 36.6% of postgraduate (taught) and 43.2% of postgraduate (research) students [16]. **Figure 1.1** shows that approximately 76% (207,755) of international students were domiciled outside the EU in 2018/2019. The greatest number of students coming from the non-EU countries was from China, with 86,895 first-year Chinese students (representing approximately one in every three international students in the UK), followed by India and the United States with 18,305 and 12,390 first-year students enrolled in 2018/19, respectively. The remaining 24% of international students (65,165) came from one of the EU countries. The country providing the highest number of EU domiciled students in 2018/19 was Germany, with 7,245 students, closely followed by France and Italy, with 6,830 and 6,180 students, respectively [17].

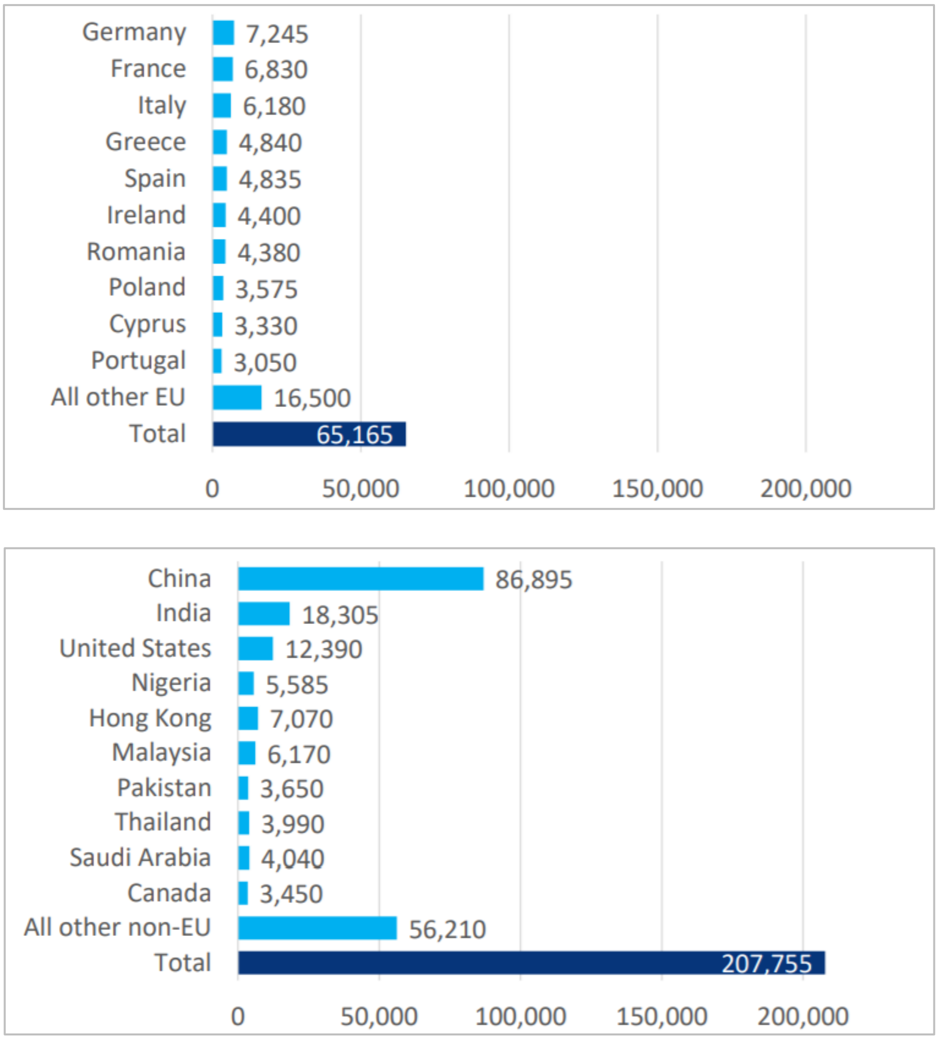


Figure 1. 1 *International first-year students enrolled in UK higher education in 2018/2019 a) Top 10 EU and b) non-EU countries of domicile by respectively [18]*

Culture, one of the essential components of an individual, delineates the characteristics of a group with similarities such as language, religion, tradition, and ethnicity. Knowing the cultural background of a group of people is vital because it could help understand why a group of people acts similarly compared to another group. In the field of lighting environment, Pierson et al. [18] have used the term of ‘culture’ as “the climatic and indoor conditions to which the subjects have been accustomed during the major part of their lives, their behaviours toward this indoor environment, and their expectations about it”.

International students coming to the UK mostly travel from countries with a wide range of daylight conditions that differ from each other and from the daylight conditions found in the UK (e.g., China, Malaysia, the United States, Nigeria, India, Germany, France, Italy and Ireland) [16]. Outside daylight conditions refer to the amount and duration of daylight varying with the sun's position in the sky depending on latitude and atmospheric conditions that depend on various factors (e.g. turbidity, climate, pollution). Hence, students from different parts of the world could be assumed to have previously experienced different lighting environments, and students from locations with similar daylight conditions should have comparable daylight expectations. To this end, students' cultural diversity and the specific lighting environments they were accustomed to in their country could affect their perception and expectation towards the outdoor and indoor conditions they found in the United Kingdom.

Maintaining the students' satisfaction with the indoor environment they found in the UK is essential because the indoor environmental quality is highly associated with the occupants' comfort and health and well-being [19]. Daylight, in particular, has a pivotal role in physiological, psychological, and behavioural influences on human health and well-being by influencing the body through its circadian rhythm beyond being just an environmental parameter [20] [21]. As a consequence of settling in a new location, students' environmental judgements may vary, and their academic performance, and more importantly, health and well-being, could be influenced differently from each other in the conditions that they are not accustomed to, due to the accustomed lighting conditions in their home countries.

1.2. Aims and research questions

To date, few studies have explored the relationship between cultural background and daylight perception; however, those studies have mainly focused on glare sensitivity regardless of daylight intensity. Cross-cultural studies aiming to investigate lighting preferences in interior environments are also rare and what is not yet known is the importance of cultural background and its impact on daylight perception, expectation and satisfaction.

The aim of this study is to investigate whether individuals perceive daylight conditions differently from each other due to their cultural backgrounds by developing a methodology to assess individuals' daylight perception and its application in the context of cultural background. To achieve the aim of the research project, it seeks to address the following research questions:

RQ1. What are the most commonly used methods for assessing individuals' daylight perception?

RQ2. What does "culture" mean, and what are the key elements of cultural background in the lighting environment?

RQ3. Does cultural background affect how people perceive daylight, and if so, how?

This thesis has been structured in the way that each chapter supports the research question in the following chapter, as well as the main research question. Each chapter has its own literature review, methodology, result and conclusion sections and the research objectives to achieve the aim of the research project are summarized as follows:

- To review the methods that were previously used to assess daylight perception
- To compare the perceived daylight availability obtained from some of these methods to actual daylight conditions
- To investigate the role of daylight availability in students' seat selections and subjective statements
- To assess the relationship between the lit area drawn by participants as part of the daylight boundary line method and actual daylight availability
- To determine whether desks with high illumination are preferred by students by analysing the occupancy pattern of the desks in the library in relation to daylight availability
- To develop a methodology for calculating individuals' daylight exposure based on subjective statements from participants
- To develop a methodology using the external illuminance of cities that participants came from as an indicator of long-term daylight exposure of participants
- To categorise daylight measurements in accordance with lighting guidelines in order to determine their sufficiency and to assess participants' subjective responses based on them
- To define the components that could be used to describe "culture" of participants in the lighting field
- To establish a methodology for assessing the daylight perception of participants in the context of their cultural backgrounds
- To develop a methodology depending on the previously identified “cultural background” components to examine the influence of cultural background on the students' individual daylight assessment in the Bartlett Library
- To give some recommendations for future research and practical application

1.3. Contribution of the study

The degree of occupants' satisfaction with the indoor environment, in particular with daylight conditions, greatly impacts individual mood, behaviour and cognitive performance [22]. Therefore, gaining a better understanding of students' daylight perception and expectations could increase their satisfaction with the indoor environment and also their cognitive and academic performance. This is especially important to individuals migrating for study purposes for a short period (e.g. MSc students) who need to adapt to new environments and concentrate on their studies as quickly as possible. London takes the lead in the UK with £2.74 billion in education export earnings [15] from approximately 100,000 international students annually [13], which constitutes one of three student immigrants in the UK [14]. Therefore, the variation in the geographical and cultural background of students coming to London provides an opportunity to explore whether the variation in the cultural background affects daylight perception.

The lighting researchers, architects, and industry practitioners can utilise the study results to design spaces that consider the various cultural backgrounds of students to increase their satisfaction with the luminous indoor environment. Some findings could be further developed into design guidelines for lighting design. Knowing about occupants' lighting expectations due to cultural experiences could also help meet the occupants' needs and preferences and provide occupant satisfaction, which in turn helps reduce unnecessary energy consumption in the built environment. Therefore, this knowledge can also be utilised by managers and daily operators of university buildings to help reduce the energy consumption from illumination systems and HVAC (Heating, Ventilation, and Air Conditioning). For instance, a study on Korean office buildings showed that adjusting the indoor lighting conditions based on occupants' expectations and utilisations helped to reduce lighting energy consumption by up to 43% [23].

Moreover, it can support architects and lighting professionals working in the design of educational and dormitory buildings. For instance, the study results can help architects better design libraries, where the role of daylight on seat preference alongside other factors can be crucial in achieving functional, comfortable and high-quality spaces.

1.4. Thesis structure

This thesis comprises seven chapters, a summary of which is given below and illustrated in **Figure 1. 2** at the end of this section.

CHAPTER 1: Introduction briefly summarises the context of the study, the aims, and the research objectives. Following this introductory chapter, the first part of **CHAPTER 2: Literature review** reviews what is currently known about the impact of daylight on human health and well-being. The second part intends to provide an overview of daylight perception to establish the extent to which assessment methods of daylight perception have been used commonly and develop research questions to be investigated. After identifying the evaluation methods of daylight perception, **CHAPTER 3: Evaluation of daylight perception assessment methods** presents a comparison of different methods for assessing daylight perception using a pilot study that investigates which methods are more associated with individual daylight assessments. Seating preference of the students, one of the quantitative measures used to assess daylight perception, needed further investigation and therefore, an analysis was conducted and presented in **CHAPTER 4: Investigation of the role of daylight availability on seat preference** considering the association between occupancy data of the desks in the Bartlett Library and daylight availability to prove that daylight conditions promote students to select specific places.

Following the identification of the methods for evaluating daylight perception, a conceptual framework of cultural background in the lit environment was needed to answer the question of what is the impact of cultural background on daylight perception. **CHAPTER 5: Cultural Background In The Lit Environment** presents a systematic review and identifies the main components of cultural background in the lighting environment. It describes a review of previous research to establish how the cultural background impacts daylight perception with different approaches. Following the definition of cultural background on daylight perception, **CHAPTER 6: Investigation of the influence of cultural background on daylight perception** aims to develop a method depending on the previously identified components to examine the influence of cultural background on the students' individual daylight assessment in the Bartlett Library. Lastly, **CHAPTER 7: Conclusions and future research** summarises the work presented in the previous chapters and discusses the findings concerning previous research. It provides overall conclusions and potential implications for daylight perception research and concludes with future research suggestions.

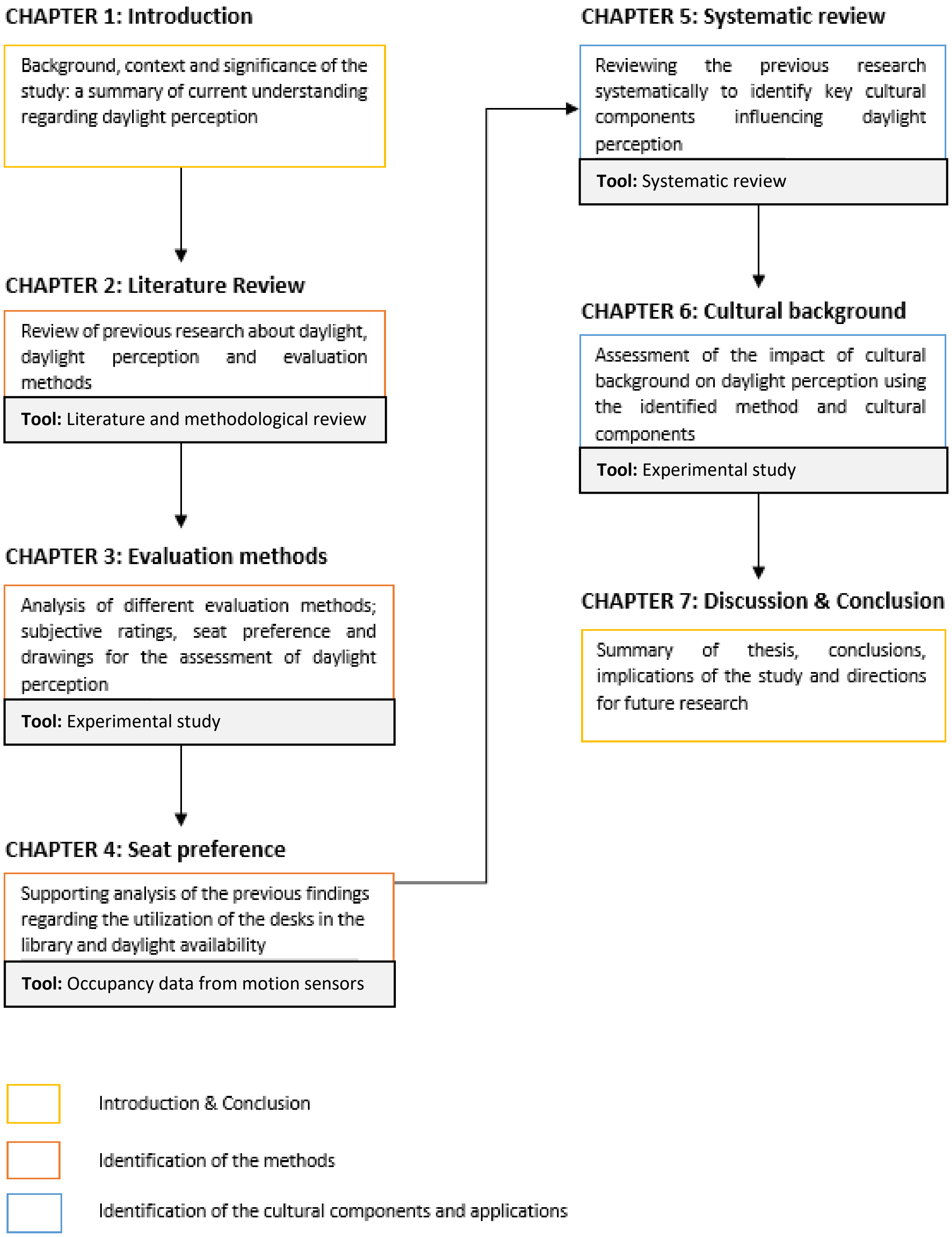


Figure 1. 2 Overview of the thesis

1.5. Publications from this thesis

A total of four peer-reviewed journal papers (published, works in progress) and three conference papers are derived from this thesis, as follows;

Published papers

- Izmir Tunahan, Gizem; Altamirano, Hector; Unwin Teji, Jemima; Ticleanu, Cosmin; (2022) **Evaluation of Daylight Perception Assessment Methods.** Frontiers in Psychology, 13, Article 805796. 10.3389/fpsyg.2022.805796.
  The relevant PhD chapters are "Chapter 2 and Chapter 3."

- Izmir Tunahan, Gizem; Altamirano, H; Unwin Teji, Jemima; (2021) **The role of daylight on user's seat preferences.** In: Proceedings of the CIE 2021 Conference (International Commission on Illumination). CIE (Commission Internationale de l'Eclairage)
  The relevant PhD chapters are "Chapter 3 and Chapter 4"

- Izmir Tunahan, Gizem; Altamirano, H; Unwin Teji, Jemima; (2021) **Conceptual Framework of Cultural Background in the Lit Environment.** In: Proceedings of the CIE 2021 Conference (International Commission on Illumination). CIE (Commission Internationale de l'Eclairage)
  The relevant PhD chapter is "Chapter 5"

- Izmir Tunahan, Gizem; Altamirano, H; Unwin Teji, Jemima; (2021) **The impact of daylight availability on seat selection.** In: Proceedings of the IES 2021 Annual Conference. Illuminating Engineering Society (IES): New York (NY), USA.
  The relevant PhD chapter is "Chapter 3"

Paper under review

- Izmir Tunahan, Gizem; Altamirano, Hector; **Seating behaviour of students in the UCL Bartlett Library before and after COVID-19** (submitted to International Journal of Environmental Research and Public Health in September 2022)
  The relevant PhD chapter is "Chapter 4"

Publications in progress

- Izmir Tunahan, Gizem; Altamirano, Hector; Unwin Teji, Jemima; **The impact of cultural background on daylight perception.** (In progress) (intention of submission to Journal of Frontiers, Environmental Psychology section in December 2022)
  The relevant PhD chapters are "All chapters in the thesis"

- Izmir Tunahan, Gizem; Altamirano, Hector; Unwin Teji, Jemima; **A new approach to the assessment of subjective daylight exposure** (In progress) (intention of submission to Journal of Lighting Research and Technology in February 2023)
  The relevant PhD chapter is "Chapter 6"

- Izmir Tunahan, Gizem; Altamirano, Hector; Unwin Teji, Jemima; **Development of a methodology for assessing various characteristics of library seats and Application of the methodology to UCL libraries** (In progress) (intention of submission to Journal of Frontiers, Environmental Psychology section in May 2023)
  The relevant PhD chapters are "Chapters 3 and 4"

CHAPTER 2: Literature review

2.1 Introduction

Individuals spend a significant amount of time indoors, more than 90% in developed countries. Hence, the indoor environment in buildings has a pivotal role in occupants' health, well-being, satisfaction, and productivity [24]. Lighting, one of the critical environmental factors that influence human comfort in the built environment, has an undeniable impact on the occupants' health and well-being in addition to thermal, acoustic, and air quality components [25]. Light is not only required for vision but also for a wide range of non-visual functions operating through the circadian system. Lighting conditions could influence the occupants' mood, health and safety, and aesthetic judgments. It also helps to enhance visual, task and behavioural performance as well as social interactions [26].

In addition to the contribution of lighting to human health and well-being, adequate lighting conditions can help reduce the operational costs of buildings and increase occupant satisfaction and productivity [27] because occupants' dissatisfaction with lighting conditions could cause an increase in the operational costs of the building [3] [28].

2.2. The impact of daylight on health and well-being

Previous studies have primarily defined lighting as an essential factor for human life to provide visual information and ensure people do everyday tasks efficiently [29]. In 1722 Dutchman Antony van Leeuwenhoek remarked on a visual effect mechanism by discovering photoreceptors called rods and cones that capture lighting information in the eye retina [21], as confirmed by the German Gottfried Treviranus in 1834 [30]. This pioneering discovery provided to gain an understanding of the mechanism of sight. A large volume of studies, which described the photoreceptors' role in converting the light energy into neural activities in the retina, were published in the forthcoming years [30]. These photoreceptors, which enable people to see while the rods differentiate from cones with colourful vision [31], remained the only recognised photoreceptor cells in the retina for 150 years. More recently, Berson, Dunn, and Takao [21] made a ground-breaking contribution to this knowledge by proving the existence of a novel, third-type photoreceptor called intrinsically photosensitive retinal ganglion cells (ipRGC). This novel photoreceptor controlled by the mechanism of light and darkness has been considered substantial because of the biological effects of lighting on human health and well-being [30].

Recent studies have explained the mechanism of the third photoreceptor, which includes melanopsin and caused radiations to have the ability to stimulate many physiological responses in animals and human beings [32]. The most significant physiological response of the body is to stimulate and manipulate the neurons that control the circadian rhythm. Circadian rhythm is a 24-hour internal clock and is responsible for regulating many physiological (body temperature and hormones) and behavioural (sleep, mood, alertness, and performance) changes [20] at regular intervals [21].

Apart from the biological clock function, the regulation of some important hormones, such as melatonin (sleep hormone) and cortisol (stress hormone), is carried out by ipRGC through daily and seasonal rhythms of the body process. Cortisol and melatonin hormones are crucial for people since they play a significant role in regulating the alertness and sleeping of individuals. Cortisol is responsible for increasing blood sugar to convey body energy. It reaches the highest level in the morning while remaining at a sufficient level during the bright day and drops to the minimum level at midnight. Opposite to the function of cortisone hormone, melatonin falls down in the morning to provide more alertness, reaching the highest level at night (**Figure 2. 1**). As evidence of the non-visual functions of lighting, some studies have shown that blind people could perceive photic changes despite the degenerated rods and cones in their retina [31]. Consequently, even blind people could have sleep phases and related problems due to circadian distribution [33].

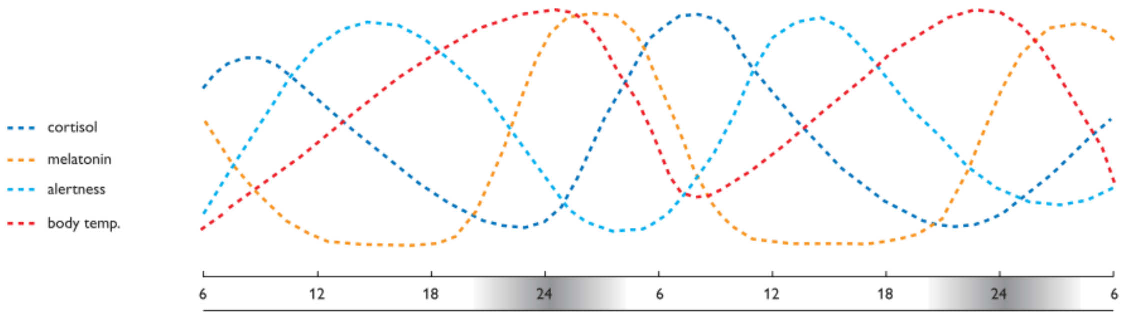


***Figure 2. 1** Typical daily rhythms of body temperature, alertness, melatonin, and cortisol levels in a 2 x 24 hours light/dark cycle* [30]

In addition to the hormone changes and effects in the body, as shown in **Table 2. 1**, non-visual lighting has undeniable effects on human health and well-being. Some existing studies have asserted that it is possible to use non-visual lighting to promote an increase in physical activity participation [34], enhance human creativity [35], change clothing preferences [36] and even change social behaviours that may encourage people to help others [37].

***Table 2. 1** Physiological and psychological effects of daylighting on health and well-being*

Physiological benefits		**Psychological benefits**	
Improvement	**Reduction**	**Improvement**	**Reduction**
Vitamin D [38]	Cancer probability [39]	Mood and social interaction [40]	Risk of depression [41]
Visual Performance [42]	Abnormal bone formation [43]	Mental and cognitive performance [44]	Stress level [45] Suicide frequency [39]
Circadian Rhythms [46]	Work-related headache [47]	Alertness [48]	Sadness [41]
Sleep Quality [49]	Cardiovascular disease [43]	Brain function [50]	Selfish behaviours [37]

Apart from the physiological and psychological impact of daylight, the association between luminous conditions and health, well-being, and task performance, has been represented in a conceptual model [51] [52] [53], which comprises two pathways; the appraisal and vision path (**Figure 2.2**)

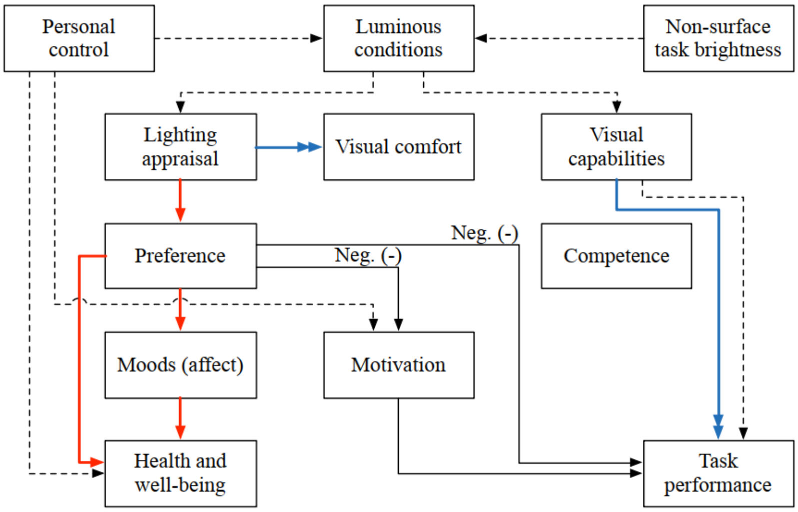


Figure 2. 2 *The linked mechanisms map* [53]
(Red solid lines show the Appraisal path, and Blue solid lines show the Vision path)

The appraisal path consists of the self-assessment of lighting quality in a space. It shows that an increase in lighting quality helps increase occupants' health and well-being. Even though this appraisal path demonstrates a comprehensive conceptual model regarding the impact of lighting quality on occupants' health and well-being, the role of individual differences in the lighting appraisal and, ultimately, preference and task performance in the lighting environment specifically remains to be understood deeply. It shows that occupants' task performance in the luminous environment needs further investigation depending on their individual differences and preferences.

2.3. The impact of daylight on cognitive and academic performance

2.3.1 Cognitive performance

The workplace environment, where individuals spend considerable time [54], could enhance or detract from people’s satisfaction, performance, and well-being. Therefore, it is crucial to design workplaces that promote employees' experience rather than worsen it [6]. Similarly, the quality of schools and their learning environments can considerably impact students, affecting their cognitive and academic performance [5].

To date, several studies have linked daylight exposure with cognitive performance. The systematic review conducted by Court [28] showed that people exposed to daylight conditions for prolonged hours had a higher cognitive performance. The researcher provided reasonably consistent evidence of an association between daylight and productivity. It was also stated that any type of alternative electric light cannot replace daylight and cannot provide benefits to health and well-being as natural light.

Another study [6] assessed the impact of occupants’ satisfaction and cognitive performance using two shading systems designed to provide optimum daylight and outdoor view conditions. In this study, occupants exposed to somewhat daylight were more satisfied, and their cognitive performance was much higher compared to the baseline conditions with no daylight exposure and outdoor view. Memory updating, inhibition, and task switching were assessed as three dimensions of cognitive performance. Study findings demonstrated that cognitive performance functions were increased with exposure to daylight and outdoor view; however, all three dimensions were not affected to the same degree.

Likewise, a study conducted by Chinazzo, Wienold and Andersen [55] investigated the effect of melanopsin photopigment, a type of light-sensitive retinal protein, on human cognitive regulation, which refers to how well the learner can regulate his/her own learning system, i.e., goal setting, choosing and applying strategies, and monitoring his/her actions. With this intention, sixteen participants were tested according to (1) their adaptation to light; using a different type of wavelength exposure (461, 515, 589 nm) for 10 min, (2) simple auditory detection tasks in an MR scanner, (3) exposure to darkness - 70 min and (4) a more difficult auditory working memory task at 515 nm in the MR scanner for 15 min. As a result, it was found that the wavelength of light to which individuals had been exposed prior to each recording affected their executive brain responses, particularly when they were exposed to the longer wavelength of light (589 nm) more than an hour before the experiment.

The same researchers [55] conducted another study where cognitive performance was evaluated under controlled daylight levels at different indoor temperatures. In the experiments, eighty-four participants were randomly exposed to three daylight illuminance levels with one of three predefined temperature conditions. The researchers assessed participants' cognitive performance using objective evaluations (quantitative assessment with measurements) and subjective evaluations (statements and expressions of the participants). For this aim, three paper-based assignments were used to evaluate the distributed visual attention, sustained vigilance and logical reasoning. Also, individual evaluation questionnaires were used to assess participants' differences in personal conditions. Researchers pointed out that self-assessment of concentration levels was highly associated with daylight exposure, especially at low concentration levels when exposed to low illuminance levels. However, objective evaluations were not influenced as much as subjective evaluations by daylight illuminance or its interaction with temperature conditions.

The impact of daylight exposure on cognitive performance was also assessed in depressed versus non-depressed patients using insolation (daylight exposure) data of 16,800 participants from a national cohort study [56]. The researchers examined whether the duration of daylight exposure influences the probability of cognitive impairment among depressed and non-depressed participants. In this study, the exposure to daylight was found more influential on the cognitive performance status of depressed participants than non-depressed ones. The researchers also demonstrated that continuous two-week exposure to daylight was more associated with the cognitive performance status of participants (p=0.005) than same-day exposure.

2.3.2 Academic performance

The previous section demonstrated that daylight exposure significantly impacts the students' cognitive performance and, correspondingly, students' academic performance and achievement. In this respect, Shishegar and Boubekri [5] reviewed the current literature on daylight, and they demonstrated that health, satisfaction, attention and ultimately, the success of workers and students are enhanced by daylight. Supporting their findings, another study [57] assessed the math and reading test results of a large population of students based on the daylight conditions of their classroom with control variables such as teacher experience and the demographic characteristics of each school. The researchers demonstrated that the results from math and reading tests were up to 20% higher for students attending classrooms with daylight or skylight compared to those attending classes in a classroom with no daylight or skylight. Similarly, Taylor, Enggass, and Pressman [58] proved that students taking math and reading tests in classrooms with the most daylighting performed 20% and 26% faster, respectively, compared to their peers in classrooms with little or no daylight during an academic year.

The impact of daylight on the academic performance of the students was also positively appraised by Edwards and Torcellini [59], considering class attendance as an indicator of students' academic performance. The researchers reported that students' class attendance increased from 3.2 to 3.8 more days per year when conventional fluorescent lighting is replaced by full-spectrum fluorescent lights, which mimic the properties of natural light; however, they cannot be superseded by natural light exactly. The researchers also stated that students' class attendance rate at that school became over 98 per cent after replacing the conventional lights. Moreover, fewer absences due to health issues were reported compared to the surrounding schools.

Likewise, another study examined the impact of artificial lighting mimicking daylight on concentration and cognitive performance. The so-called ‘’biologically optimised’’ light was produced from a combination of blue and white LEDs to create an artificial sky in the classroom. The students between 17 and 20 attended the classes in both classrooms with biologically optimised and traditional lighting systems, and they were instructed to perform several performance and concentration tests repeatedly. Study results showed that students under biologically optimised lighting systems performed faster and got higher scores on concentration tests than those under traditional lighting systems. Supporting that, other researchers [60] investigated whether daylight exposure was associated with objectively measured physical activity and sedentary behaviour in young people. Their research demonstrated that daily average light exposure is positively associated with time in physical activity and negatively associated with sedentary time. The researchers concluded that increasing daylight exposure might help promote people's physical activity. Other researchers [61] also studied students’ academic performance and health, and they found out that working in classrooms without windows caused a remarkable change in students’ cortisol hormone level, which is linked to stress and could have a detrimental effect on the health and concentration of students compared with classrooms that have access to daylight.

2.4 Daylight perception and evaluation methods

Up to now, much research has demonstrated the link between daylight exposure and cognitive and academic performance. It was remarked that daylight could increase students' academic success, promoting physical activity and more class attendance and positively influencing health and concentration. However, the role of individual daylight preference and expectations of students on their cognitive and academic performance still remains to be established. In order to investigate how individuals’ daylight preferences influence their cognitive and academic performance, it is necessary to understand daylight perception and assessment methods.

2.4.1. The concept of daylight perception

Daylight perception represents people's feelings against daylight conditions and their satisfaction level with daylight conditions, which could influence their preferences, expectations and behavioural decisions. Understanding the complexity of daylight perception could have numerous advantages since the degree of satisfaction, in particular with daylight conditions, greatly impacts individual mood, behaviour and cognitive performance. Most importantly, this knowledge could help meet the occupants' needs and preferences, which in turn help increase occupant satisfaction with the indoor environment and reduce the unnecessary energy consumption from both HVAC (Heating, Ventilation, and Air Conditioning) and illumination systems in the built environment. For instance, a study on Korean office buildings showed that adjusting the indoor lighting conditions based on occupants' expectations and utilisations helps to reduce lighting energy consumption by up to 43% [23]. However, lighting research on daylight perception to date has focused on glare discomfort perception and colour temperature preference, but not on the adequacy of the illuminance levels.

2.4.2. Assessment methods of daylight perception

In order to create a framework of the methodological approach to assess daylight perception in the literature, 482 research articles published in Scopus, Web of Science, and LEUKOS databases were searched for electronic records. The search was done in either title, abstract, or keywords of the papers using the following keywords: (Day)light perception, (Day)light expectation, (Day)light satisfaction, (Day)lighting sensitivity, (Day) lighting tolerance and (Day)light adaptation. The inclusion criteria were: (a) including at least one aspect of (day)lighting perception, (b) published in English, peer-reviewed journals excluding conference proceedings and books, and (c) published during any year from 1990 to November 2021. Relevant articles were classified depending on their methods and reported in **Table 2. 2**.

2.4.2.1. General approach

Various methods have been developed and used to investigate how lighting conditions are consistent with human perception of daylight and daylight expectations. These methods have been applied in either real-world environments [62] or laboratories under specified testing conditions [55] [63] [64]. Even though real-world environments provide an opportunity to conduct studies in a dynamic social context, people being observed cannot be tested under diverse environmental conditions. Conversely, participants in laboratory settings know they are the subject of study, which may affect their behaviour, making it challenging to associate results with real-life situations [62]. Nevertheless, laboratory studies enable researchers to investigate changes when daylight conditions are changed [65] [66], which cannot be tested in real-world environment studies.

Although most methods and tools used in assessing daylight perception differ, their general methodological approach is similar; it combines subjective and objective measurements and assesses them depending on the existing lighting conditions collected by either spot measurements or daylighting simulations. The studies are also often supported by circadian rhythm parameters, such as cognitive performance, alertness, sleep quality, and mood. Nevertheless, almost all studies have used one or more methods to assess the changes occurring in daylight perception concerning the variation in the luminous environment (**Table 2. 2**).

2.4.2.2. Methods regarding circadian regulation

Circadian rhythms are approximately 24-h cycles controlled by an internal master clock in the brain responsible for regulating many physiological (body temperature and hormones) and behavioural (sleep, mood, alertness and performance) changes [20]. Circadian rhythms are mainly affected by the intensity and timing of light exposure [67] and are adjusted at regular intervals by receptors transmitting non-image-forming information of light, which activate the circadian system [21].

Exposure to a high amount of daylight (for example, spending a large amount of time outside or sitting indoors by a big window) has been shown to enhance students' cognitive and academic performance [5]. Previous research that examined the impact of different shading systems on cognitive function performance, satisfaction, and eyestrain in a living lab has also established that satisfaction with indoor daylight conditions could result in higher cognitive performance [6]. Most researchers have benefitted from commonly used tests and techniques such as the Psychomotor Vigilance Test (PVT), usually used to assess the link between daylight and cognitive performance. Others have also used class attendance or typing speed and accuracy as an indicator of cognitive performance.

On the other hand, several studies have proved that daylight exposure significantly influences occupants' mood states [68]. Küller et al. [69] indicated that the participants' mood reached the lowest level when describing the daylight conditions as too insufficient. Specified scales such as the Perceived Stress Scale (PSS), the Positive and Negative Affect Schedule (PANAS), the Centre for Epidemiologic Studies Depression Scale (CES-D) and the Visual Analogue Scale (VAS) [65] [70] and specified questionnaires such as the General Health Questionnaire (GHQ) [66] are usually utilised to investigate the association between the exposed daylight conditions and mood states.

Changes in circadian rhythms have also been associated with sleep quality and alertness, in addition to mood and cognitive performance [71]. The Karolinska Sleepiness Scale (KSS) has been mainly used to measure both subjective sleepiness and alertness [72] [55]. Tools such as the Horne and Ostberg Morningness-Eveningness Questionnaire and the Munich Chronotype Questionnaire have also been used to assess the sleep quality of participants grouped according to their sleep-wake behaviour (morningness-eveningness) [73][74].

2.4.2.3. Physiological biomarkers as a consequence of exposure to daylight

Physiological measurements (biomarkers) are regarded as indicators of previous light exposure; in other words, how much a participant was exposed to light during a specific time. The duration, timing and intensity of exposed daylight may affect people's satisfaction with current daylight conditions and the regulation of their circadian rhythms. Thus, the assessment of physiological biomarkers could play a crucial role in assessing and interpreting an individual's daylight perception.

The objective measurement of daylight perception considers the assessment of physiological biomarkers such as heart rate [75] [76], skin conductance [75] [77], core body temperature [78] [76], cortisol level [74] [70], and melatonin secretion [74] [65]. Heart rate, skin conductance, and body temperature have been measured using wristbands, while melatonin secretion is measured using either salivary, blood, or urine samples. Almost all studies reviewed in this study utilised heart rate and melatonin secretion data, while some researchers also benefited from skin conductance, core body temperature, and cortisol level measurements.

2.4.2.4. Subjective assessment of daylight

Since individuals are physically and psychologically influenced by daylight [32], objective measurements should be complemented with subjective evaluations. However, some studies [79] [80] [81] have shown that correspondence between exposed daylight conditions and subjective assessment of the occupants is not always observed because of individual differences.

Subjective assessment methods mainly use questionnaires to obtain information through semantic differential techniques, measuring the participant's overall reaction to specific factors such as ambient illumination of different light sources or horizontal illuminance and brightness of space [82] [83]. Similarly, open-ended questions are used to gain deeper insights into the feelings towards daylight conditions, for instance, how participants describe the lighting conditions and how they feel under those conditions. Researchers have benefitted from questionnaires with various types, purposes and distribution ways, e.g., verbal, e-mail, online, paper-based, or computer screen. Generally, most of them have conducted studies with commonly used lighting-related questionnaires either directly or modifying them. Information is usually collected concerning the participants' background (age, gender, work schedule, sleep and wake times, previous daylight exposure etc.), their evaluation of daylight illuminance and distribution, and their general satisfaction with the indoor environment [84].

As stated previously, previous daylight exposure could play a vital role in the subjective assessment of daylight because exposure to a certain amount of daylight during a specific time significantly impacts human circadian rhythms. Information about previous daylight exposure is collected with the use of devices that participants are asked to wear, e.g., wristbands, Daysimeter and the ambulatory circadian monitoring device (ACM) [75] before [65] and/or during the experiment [85]. The collected data is often supported by self-written logs [73]. These devices are also used to gain insight into the activity and sleep patterns of the participants and the amount of daylight they were exposed to. However, sometimes the measurement of daylight exposure using specific devices may not be feasible and accessible to researchers and practitioners [86]. In this case, researchers may quantify the daylight exposure of the participants using some questionnaires.

As a method for assessing previous daylight exposure, questionnaires require participants to state and estimate their daylight exposure in a particular period [73]. For instance, the Munich ChronoType Questionnaire (MCTQ) involves estimating the time spent outdoors on workdays and free days, assuming regular light exposure patterns. Likewise, the Harvard Light Exposure Assessment questionnaire (H-LEA) emphasises the importance of time duration and period of light exposure during the daytime to various artificial and natural light sources.

Few researchers have preferred other subjective methods, such as interviews, to test the influence of different daylighting configurations on participants' daylight perception [87] [88]. Moreover, some evaluation techniques, such as seat selection, have been applied, where it has been assumed that daylight perception and expectation are associated with seat preference and window location [89] [90]. In this case, the selected desk's illuminance level could be used as an indicator of daylight perception. Additionally, a unique method was proposed by Reinhart and Weissman [30] and also used by Handina et al. [31], given its potential as a representation tool of how daylight composition can be perceived in a space. Handina et al. [31] have considered the daylight boundary line method to assess perception through the definition of daylit and non-daylit areas drawn by participants. In this methodology, participants have been required to draw a line whenever they notice a boundary between brightness and darkness in the experiment room. Their initial results showed that the percentage of the area enclosed with the contour line of DA300 lx, 50% (illuminance level of at least 300 lux over at least 50% of the space) in the observed space (55%) is close to the partially daylit area (56%), which is the area perceived as bright by at least 25% of participants. Furthermore, high Dynamic image techniques [86] and 3D daylight renderings [91] have also been used to evaluate the human perception of the daylight composition found in shown scenes. In the further development of these techniques, subjective daylight perception under various computer-generated conditions has been assessed using scenes displayed with the Immersive virtual reality (VR) technique [64] [92].

Table 2. 2 *Evaluation methods of daylight perception*

A - Assessment of circadian daylight

B - Physiological assessment of daylight perception

C - Subjective assessment of daylight perception

Assessment of circadian daylight		
Method		**References**
Cognitive performance	**n-back test** to measure working memory and working memory capacity	[74]
	CNV test to measure work performance with the average response times of correct answers **Arithmetic task** to reflect work performance with the ratio of correct answers	[63]
	Tsai Partington to evaluate the distributed visual attention **d2 test** to evaluate the sustained vigilance **Baddeley test** to evaluate the logical reasoning	[55]
	Psychomotor Vigilance Test (PVT) including a Simple Reaction Time (SRT) test, a 2-Forced Choice Reaction Time (FCRT) test, and a Matching-to-Sample (MTS) test.	[65]
	Observation of Typing speed and accuracy	[72]
	Eye-tracking for measure numbers of fixation with a device such as Tobii® T60 Eye Tracker	[72]
	Class attendance as a measure of students' performance	[59]
Alertness	**Visual Analogue Scale (VAS)** to assess fatigue and alertness	[66]
	Karolinska Sleepiness Scale to measure both subjective sleepiness and alertness	[72] [55]
Sleeping pattern	**Subjective sleepiness** with some surveys such as the 9-item Karolinska Sleepiness Scale (KSS) and Sleep Habits Survey	[74] [93] [66] [65] [70]
	Sleep-activity behaviour A daily sleep-activity graph during the experiment	[73]
	Identification of morningness-eveningness Horne and Ostberg Morningness-Eveningness Questionnaire, Munich Chronotype Questionnaire (MCTQ) and Composite Scale	[73] [74] [93] [78]

Mood	**Psychosocial stress** assessment with Perceived Stress Scale (PSS)	[65]
	Mood assessment with the Positive and Negative Affect Schedule (PANAS) and the Centre for Epidemiologic Studies Depression Scale (CES-D)	[65]
	Subjective general health evaluation using GHQ questionnaire	[66]
	Subjective mood and visual comfort using visual analogue scales (VASs)	[70]

Physiological assessment of daylight perception	
Method	**References**
Heart rate (HR) using some devices such as the Empatica E4 wristband	[75] [76] [94] [77] [95] [63]
Skin conductance (SC) using some devices such as Empatica E4 wristband and Electrodermal activity (EDA) wristband	[75] [77] [95] [76]
Core body temperature using some devices such as iButtons data loggers and wristband	[78] [76]
Cortisol level from salivary	[74] [70]
Melatonin secretion from salivary, blood, urine	[74] [65] [70] [63] [96] [66]

Subjective assessment of daylight perception		
Method		**References**
Interviews	Informal or semi-structured	[87] [88] [97] [63]
Questionnaires	**Questionnaire-based survey** Snapshot subjective assessments such as Perceived lighting quality assessment and other created questionnaires mainly using a semantic differential method	[87] [98] [73] [77] [88] [55][99]
	Questionnaire-based survey Long-term subjective assessments	[100]
	Subjective evaluations during experiments within different kinds of rooms (geometry/orientation/window type/façade type), different locations and different contexts (social or working context)	[101] [75] [64] [83] [84] [94] [95] [97]
	Visual comfort evaluation such as Visual comfort on visual analogue scales (VAS), Office Lighting Survey (OLS), Lighting Conditions Survey, NRC Canada Lighting Quality Scale, IEA retrofit monitoring user assessment survey, Indoor Environmental Quality Surveys	[101] [73] [74] [72] [25]
	Indoor Environmental Quality Surveys such as Satisfaction with Environmental Features and Subjective ratings of discomfort glare (De Boer scale, Imperceptible-intolerable 4-point scale, Glare Sensation Vote, Visual comfort rating)	[25]
	Other subjective measures of lighting Descriptive scales and Lighting preferences, beliefs, and behavioural consequences	[25]
	Verbal questionnaire Evaluation of the impressions of how pleasant, interesting, and exciting the space	[75]
	Questionnaires distributed by mail to evaluate brightness and distribution	[99]

Quantification of daylight exposure consequently circadian light exposure	**Actigraphy data from wearable biometric devices** during the experiment with wristbands such as the Empatica E4 wristband	[75] [76] [93] [95]
	Actigraphy data from wearable biometric devices during the experiment with the Daysimeter	[85]
	Actigraphy data from wearable biometric devices during the experiment with the ambulatory circadian monitoring device (ACM)	[67]
	Actigraphy data from wearable biometric devices prior to the study beginning, with bed and wake times with wristbands such as Actiwatch-L	[74] [63] [78]
	Actigraphy data from wearable biometric devices prior to the study beginning, with bed and wake times with the Daysimeter	[65]
	Asking for time spent outdoors such as The Munich Chronotype Questionnaire (MCTQ), the Harvard Light Exposure Assessment questionnaire or self-prepared questions to get data about light exposure	[73]
Logs	**Weekly log** ratings of psychological well-being, daily sleep activity and time spent outdoors	[73]
	Daily sleep log prior to the study beginning.	[74] [63]
Other methods	**Seat preference surveys and observations** surveys asking for the reasons for the choice of seat locations and direct observations of actual seating behaviour	[90] [102][103] [89] [104] [105]
	Drawing daylight boundary line between daylit and non-daylit area	[106]
	HDR-High dynamic image techniques	[76] [83] [86]
	Showing daylight 3D renderings with the computer software of the same space to the subjects and asking to rate daylight composition	[91]
	Immersive virtual reality (VR) with headsets such as Oculus Rift CV1 and Oculus Rift DK2	[77] [95][75] [64]

2.5 Summary

This chapter presents an overview of current knowledge on daylight, daylight perception and methods for the assessment of daylight perception. The methodological review has demonstrated that although the methods used to assess daylight perception vary, their general approach is very similar. Participants' subjective assessments and biological measurements have generally been compared with data from real daylight measurements using luminance meters, illuminance meters, lux meters, cameras for HDR images, colour temperature meters, spectroradiometers, etc., to establish whether luminous conditions influence daylight perception. In terms of experiment design, some studies were conducted in specified test rooms with a controllable environment [55] [63] [64], and others were carried out in a real environment. Some researchers also preferred to conduct controlled experiments [65] comparing the control and experimental groups with and without one specific variable. Similarly, some researchers conducted intervention studies [66] to compare the baseline conditions with the changes that occur after exposure to any situation in the same group of people.

In order to maintain the satisfaction and academic performance of the students from different cultural backgrounds in the indoor environment they found in the United Kingdom, a methodology was needed to be developed for assessing daylight perception. For that purpose, this chapter has reviewed the methods previously used to investigate daylight perception and has provided insights that can help develop a methodology for assessing daylight perception in the context of cultural background.

CHAPTER 3: Evaluation of daylight perception assessment methods

3.1 Introduction

Daylight is an essential component in maintaining human health and well-being and plays a key role in occupants' physiological, psychological, and behavioural regulation. Understanding the complexity of daylight perception is vital since the degree of satisfaction with daylight conditions could significantly impact individuals' mood, behaviour and cognitive performance.

As highlighted in **section 2.4,** the effect of lighting conditions on human perception and expectations should be investigated using objective measurements and subjective evaluations. However, only subjective evaluation methods with different applications could be utilized to complement each other for situations where a considerable amount of data collection from objective measurements may not be feasible and accessible. Thus, in this study, seat preference, subjective ratings, and daylight boundary line drawings were used as tools to evaluate the daylight perception of participants because these methods were novel and more research was needed on them. However, more importantly, in all of them, researchers highlighted the inter-individual differences in their findings that could be a potential way of investigating the impact of cultural differences on participants' perceptions in this study.

This chapter evaluated the applicability of these three methods chosen from those previously presented methods (**Table 2. 2**) to identify inter-individual differences in students' daylight perception due to cultural background. For this aim, an experiment was conducted with students who were instructed to choose the best and worst seats, describe the best desks' daylight conditions, and draw boundary lines between perceived daylit and non-daylit spaces in a library. Obtained responsive data were compared with data from parametric modellings and daylight simulations that were validated with spot measurements representing daylight availability of the desks and spaces. Detailed information about each selected method, the rationale for selection and the method of procedure are reported in the following sections.

3.2 Methodological review

3.2.1. Subjective ratings

The subjective rating method involves asking participants to describe their feelings and satisfaction level against the general indoor lighting conditions or lighting conditions on a specific surface. This method has been utilised in various lighting studies, and many researchers have found participants’ own perceptual statements compatible with actual daylight conditions. However, subjective evaluations may not fully represent daylight availability because of individual differences in some cases.

In the lighting field, existing self-report tools used for assessing lighting quality in an indoor environment are generally used in post-occupancy evaluations of the built environment. Some well-known self-report tools in the lighting field are the Office lighting survey [51], Lighting conditions survey [107], NRC Canada Lighting Quality Scale [108] and IEA retrofit monitoring user assessment survey [4]. These tools are specified on participants' general lighting quality assessment and their satisfaction and comfort level with the indoor lighting conditions. They have numerous advantages and limitations, and these tools are generally derived from each other.

The lighting conditions survey and IEA retrofit monitoring user assessment surveys differ from other self-reporting tools covering a particular focus on daylighting [3]. They also aim to assess individuals’ feelings against specific features of lighting characteristics rather than overall satisfaction with daylight. Apart from these tools focusing on the lighting quality assessment of participants, more comprehensive indoor environmental quality surveys also exist to measure participants' overall satisfaction with the indoor environment, considering other factors affecting the indoor environmental quality, such as air quality, acoustics, thermal conditions and ergonomics in addition to lighting quality [110]. Although these brief surveys generally focus only on a few aspects of lighting quality, some tools, such as the Satisfaction with Environmental Features survey, differ from others with the substantial lighting assessment [110].

BUS (Building Use Studies) Methodology is one of the most extensively used standardised questionnaires to evaluate general occupant satisfaction with the built environment. This method consists of 45 questions regarding thermal comfort and ventilation, lighting and noise, personal control and space, design, image and needs [109]. Carrying out this questionnaire in the surrounding context is valuable in understanding and interpreting the occupants' feelings against the components of indoor environmental quality. Therefore, this study has benefited from this tool to understand the daylight perception ratings interrelated with actual daylight conditions to explore if participants describe the luminous conditions as they should be, and if not, in which way and why. The association between real and perceived daylight conditions is quite important because a deeper understanding of the possible reasons causing the variation between actual measurements and people's perceptions would help to increase occupant satisfaction with the built environment. There are also specified tools for measuring subjective ratings of discomfort glare, but they were excluded because of the irrelevance of the main theme of the thesis.

The rationale for methodology selection

Various researchers benefitted from the subjective rating method in the literature to evaluate participants' feelings and satisfaction levels against the lighting conditions. However, subjective evaluations may not fully represent daylight availability because of individual differences in some cases [81] [82] [83]. Therefore, this method was applied to determine the degree to which subjective statements represent daylight availability in space and investigate whether people perceive daylight conditions in line with actual measurements in order to explore the inter-individual differences in students' daylight perceptions due to their cultural background in further studies.

3.2.2. Seat preference

Academic libraries play a significant role in students' learning development [110]. They should provide a good learning environment that enhances students' learning ability and contributes to academic and intellectual development [111]. Although the framework for planning and designing learning spaces such as academic libraries exists [112] [113], there is still a need for a better understanding of the specific needs of students to provide environments that meet their needs and preferences [114].

The learning environment preferences have been explained in environmental psychology studies using physical dimensions (comfort, aesthetics, information and communication technology facilities, and layout), social dimensions (privacy, interaction, and autonomy), and sociodemographic dimensions (gender, age, study year, and life conditions) [115]. In other words, the preference for a learning environment is defined by the specific physical conditions of the environment and by human, cultural, and psychological dimensions. These environmental factors that affect the learning process significantly impact the students' emotions, learning ability, and feelings of belonging to space [116], hence, the students' behaviours and seat preferences in libraries [117] [118].

Seating features that meet the students' needs and preferences could aid a longer stay in the library [119], keeping students happier and motivated [89] [120]. Understanding occupant behaviour and their interaction with the indoor environment could help improve the occupants' satisfaction [121] and the energy efficiency of buildings [122] [123]. Especially for architects, it is crucial to understand and consider the factors that influence human behaviour in a library because being aware of users' preferences makes it possible to design functional, comfortable, and high-quality spaces.

Studies regarding seat preference in the learning environment have primarily focused on interior elements, such as territory, colours, and furniture [10]. However, occupant behaviour is a complex subject, as there are many external and internal aspects influencing behaviour (e.g., external environmental conditions, building characteristics, and indoor environment conditions; biological, psychological, and social aspects) [124] [125].

It has been shown that the affecting factors arising from the physical environment that govern the decision of seat selection are daylight [90] [126], ambient temperature, type of furniture, proximity to other occupants [127], quietness, outdoor view, privacy, social interactions such as close to friends, entrance or circulation [105], students' degree of territoriality and seat arrangements [128]. However, the existing knowledge of the association between daylighting and seating behaviour remains somewhat limited and needs further investigation [129].

The seat selection process also results from the individuals' prior experiences in a space or a deliberate choice among alternatives while entering the space [130], regardless of whether deciding consciously or unconsciously [131]. This assumption has also been supported by [62], indicating that seating decisions could be different for individuals familiar and unfamiliar with the physical settings in the space because the human response to the physical environment is strongly subject to prior experiences [132]. In that case, library users could repeatedly choose the same seat depending on prior experiences, whereas first-comers need to rely on external sources such as existing lighting conditions, noise levels, etc. The availability of seats at a particular time could also influence seat selection; individuals who arrive earlier at the library have more chances to select a seat than those arriving later. Individual differences, namely arousal, motivation, and expectation, also matter in human behaviour [132], influencing the decision-making process.

The rationale for methodology selection

Even though prior research revealed a variety of reasons for seat selection, a number of researchers remarked daylight as the most crucial reason for seat selection [58] and the most frequently chosen [64]. Researchers also pointed out the differences in seat selection of individuals due to their needs and expectations from the indoor environment. In this research, the seat selection method was chosen as a potential way of identifying inter-individual differences in daylight perception of students due to their cultural background in further research, considering that daylight availability at their chosen seat corresponds to their favoured daylight conditions [127] [62].

3.2.3. Perceptual daylight drawings

This unique method proposed by [133] and further used by [106] is based on the consistency between daylight availability in space and how the participants perceive and represent those conditions with drawings considering the drawings as a representation tool of participants' perception of daylight composition. This method was developed by Reinhart et al. [133], and these researchers investigated whether the human eye could determine the "300 lux boundary" (maintained average illuminance at working level) within a space without an illuminance meter. They also aimed to explore the most compatible daylight metric with the actual human daylight perception. For this purpose, students were instructed to divide and tape the floor plan of a space into a 'daylit' and a 'non-daylit' area on an arranged date and time (**Figure 3. 1**). They were also asked to carry out a series of illuminance measurements and to mark the daylit area on a floor plan of the space that they were given. Study findings pointed out that daylight autonomy (DA), defined as an illuminance level of at least 300 lux over at least 50% of the space, is the most compatible daylight metric with actual human perception. However, researchers pointed out a discrepancy between simulating daylight conditions and participants' perceptions of the indoor daylight composition, indicating that this method needs to be validated and refined in other spaces.

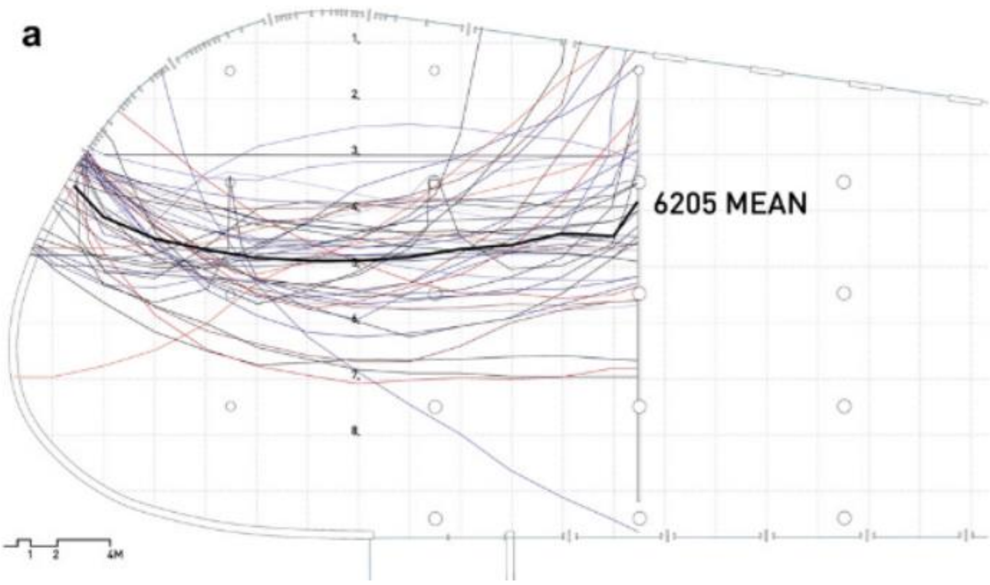


Figure 3. 1 *Example of individual daylight boundary line drawings*

A further study on the daylight boundary line drawing method was developed [106] and researchers asked participants were instructed to draw “daylight boundary lines” on a paper showing the floor plan of the building whenever a significant change of contrast which is a degree of difference between the brightness and darkness was found (**Figure 3. 2**). Following that, the researchers ran computer simulations and generated a contour plot representing a boundary line in the room crossing over 300 lux. The generated boundary line was then compared to the subjective responses to determine whether the participants' daylight boundary line drawings accurately represented the actual daylight measurements.

In order to analyse the data, researchers used the statistical quartile concept to categorise and visualise areas where a certain number of participants agreed that they were bright. Spaces were then differentiated as fully daylit (area agreed as bright by at least 75% of the participants), partially daylit (area perceived as bright by at least 25%) and non-daylit (area perceived as bright by less than 25% of participants). After that, they analysed the compatibility between participants’ perceptions and daylight simulations, overlapping the differentiated spaces based on participants' agreement with the daylight availability in those spaces. Study findings demonstrated that the percentage of the area enclosed with the contour line of the illuminance level of at least 300 lux over at least 50% of the space (DA300lx,50%) in the observed space (55%) is close to the partially daylit area (56%) which is the area perceived as bright by at least 25% of participants, in other words, they proved that participants' drawings could be used to investigate how they perceive daylight conditions. They also compared the performance of different daylight metrics in predicting the participants' daylight perception and reconfirmed that the most compatible daylight metric with participants' perception of daylight composition in space is Daylight Autonomy (DA300lx,50%) [92].

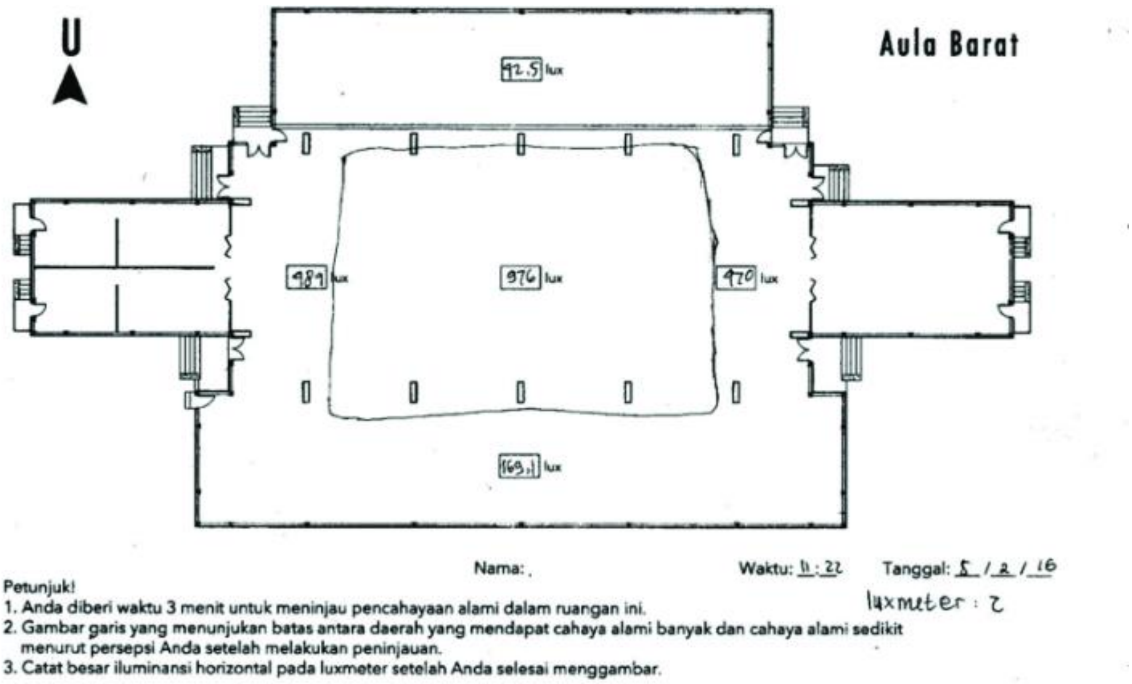


Figure 3. 2 *An example daylight boundary line drawing of a participant* [106]

The rationale for methodology selection

Although previous studies demonstrated that daylight boundary line drawings could be used to assess how participants perceive daylight conditions, they also pointed out the inter-individual differences in participants' drawings. Therefore, this unique method was chosen and applied to determine inter-individual differences in students' daylight perception due to cultural background, given that their daylight boundary line drawings represent how they perceive the daylight composition.

3.3 Methodological approach

3.3.1. General approach

Academic libraries play a significant role in students' learning development [110]. They should provide a good learning environment that enhances students' learning ability and contributes to academic and intellectual development [111]. For this reason, this study was carried out in a library, which has a high potential for investigating the factors influencing students' mood and performance, as well as inter-individual differences in their sense of belonging to a space. A previous study demonstrated that a sense of belonging to space depends on the self-concept of the physical environment factors (furniture, colour, lighting, plants, privacy, etc.), and 86% of participants stated that daylight conditions have an important role in the sense of attachment and stay in a place [134].

In order to establish a methodology to assess daylight perception in the context of cultural background, 50 MSc students were brought all together to the UCL Bartlett Library, asked to complete a questionnaire before the experiment and undertake a set of tasks while going around the library. The library was assessed during one of the sunniest days in December 2019 (between 13:00 and 14:00); a day with a clear sky was selected to get maximum daylight throughout the library during the experiment. The day and time of the study were decided based on both the previous years' lighting data obtained from Public Health England and weather data from the Met Office. All tasks within the questionnaire took between 20 and 25 minutes to complete. Subjective responses from participants were collected using various methods and compared to daylight availability obtained from daylight simulations validated by spot measurements.

3.3.2. Participants

An invitation to participate in the study was sent via email to 348 postgraduate students enrolled in MSc programs at the Bartlett School of Architecture, UCL. Seventy-six students said that they would be happy to be involved in the experiment; however, only fifty students (15 male / 35 female) aged 20-34 years old participated in this study. Eleven participants (22%) described themselves as White, whereas 33 students (66%) stated that they came from Asian backgrounds. Only five people (10%) defined their ethnicity as other ethnic backgrounds. Most of them (72%) of 50 were overseas students who had spent less than three months in London.

3.3.3. Field site

The study was carried out in the UCL Bartlett Library, London, WC1H 0NN, located on the ground floor of a six-storey building (Central House Building, Bloomsbury campus). This library was specifically selected because of the orientation of its rooms because north-facing spaces were recommended by [135] for daylight boundary line study to minimize the potential for direct sun during the experiment. The library was also selected as it contains various layouts that provide different kinds of daylighting designs.

The library comprises three main study areas (**Figure 3. 3**). The group study area (Room 1) accommodates eight shared desks and four individual cubicles and has two side windows in the north-facing external wall; the library collection area (Room 2) has twelve shared desks and eleven individual desks and several side windows facing north and east orientations; the quiet study room (Room 3) is an open-plan space with a skylight, and thirty-two shared desks. Details of the rooms and technical properties of the surfaces of walls, floor, furniture etc. are illustrated in **Appendix 1**.

Figure 3. 3 *Plan of the UCL Bartlett library (Arrows represent the perspectives of the photos taken)*

The UCL Bartlett library contains rooms with various layouts providing different daylighting designs. In addition to the general evaluation of the methods for assessing daylight perception concerning daylight availability, this study also considered zones with similar layouts, privacy, outdoor views and daylight conditions. This was especially important for the seat preference method because previous research has shown that the decision of seat selection arises not only from daylight [90] [126] but also from factors such as ambient temperature, type of furniture, proximity to other occupants [127], quietness, outdoor view, privacy, social interactions such as close to friends, entrance or circulation [105], students' degree of territoriality and seat arrangements [128]. Therefore, the analysis was also conducted considering not solely daylight but also its combination with other components. **Figure 3. 4** presents the zones with the above-mentioned common features, which were compared and illustrated in **Table 3. 1**.

***Figure 3. 4** Zoning of the library depending on the common features*

Table 3. 1 The characteristics of zones identified in the UCL Bartlett Library

ZONES	Layout	Outdoor views	Privacy
Zone A	 eight shared desks	 Church two side windows in the north-facing external wall	  not on the circulation route not facing a person sharing desk with a person limited people can see the screen distribution potentiality by staring from the window
Zone B	 four individual cubicles	no outdoor views	not on the circulation route not facing a person individual desk limited people can see the screen
Zone C	 twelve shared desks	 Church three side windows facing north	  on the circulation route not facing a person sharing desk with a person limited people can see the screen distribution potentiality by staring from the window

Zone D	 eleven individual desks	 back building facade nine side windows facing east	 on the circulation route not facing a person individual desk limited people can see the screen
Zone E	 three hot desks	no outdoor views	on the circulation route not facing a person sharing a desk with two people many people can see the screen distribution potentiality by passing people
Zone F	 open-plan space thirty-two shared desks	 skylight sky and around buildings	 not on the circulation route facing many people sharing desk with seven people many people can see the screen distribution potentiality by staring from the skylight silent room
Zone G	 open-plan space thirty-two shared desks	no outdoor views	 not on the circulation route facing many people sharing desk with seven people many people can see the screen distribution potentiality by staring from the skylight silent room

3.3.4. Quantification of daylight availability in the library

In order to assess participants' daylight perception, we needed to know how much daylight was available on the desk/space the participants pointed out. However, the measurement of the illuminance level of the desks/space was not possible using spot measurements such as an illuminance meter since all students selected the best and worst seats and evaluated the daylight availability at the best desk simultaneously. Therefore, parametric modelling, daylight simulations and spot measurements were used in this study to get information concerning daylight availability of the desks and spaces.

3.3.4.1. Parametric modelling and daylight simulations

Autodesk AutoCAD was used to produce 2D drawings of the library. The 2D drawings were exported to one of the most widely used platforms, **Rhino,** to create 3D drawings of the building. Surrounding building heights and distances from the building were obtained from https://digimap.edina.ac.uk/ created by Great Britain's national mapping agency (Ordnance Survey Limited). Then, the advanced level of Grasshopper, one of the visual programming languages, was used to create parametric modelling for lighting performance analysis. At this stage, two Grasshopper validated plugins, **Ladybug** for importing standard Energy Plus Weather files (.epw) into Grasshopper and **Honeybee** for creating, running and visualising the results of daylight simulations using Radiance, were used for lighting performance analysis (See **Table 3. 2**). The locations of the core work plane points in the simulations were defined according to the seating configuration. Reference points of each desk were shown with small red dots in the middle of the desks in **Figure 3. 3**, and daylighting simulations were conducted based on these points. The simulation process is summarized and illustrated in the below diagram (**Figure 3. 5**).

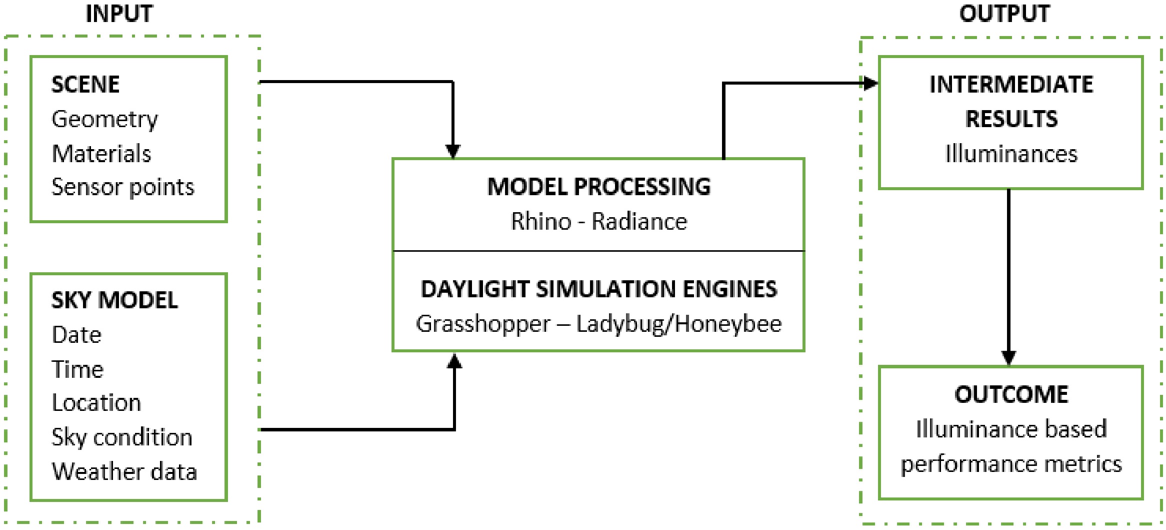
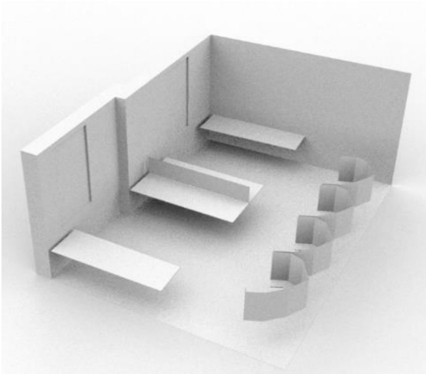
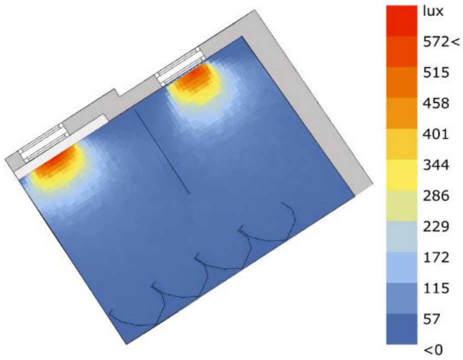
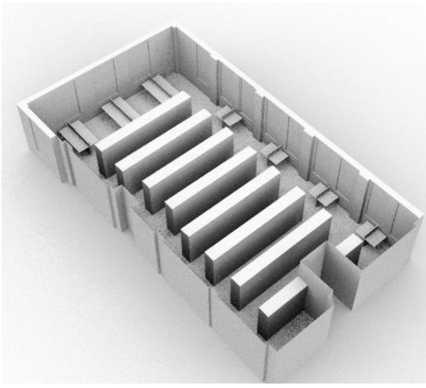
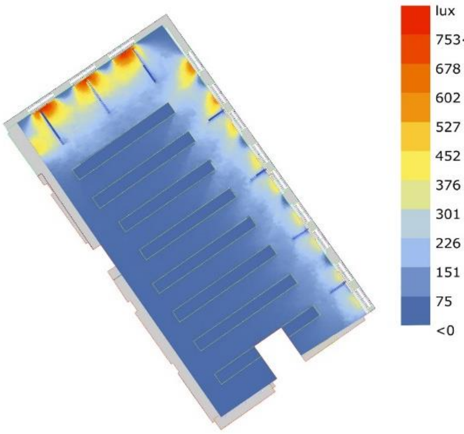
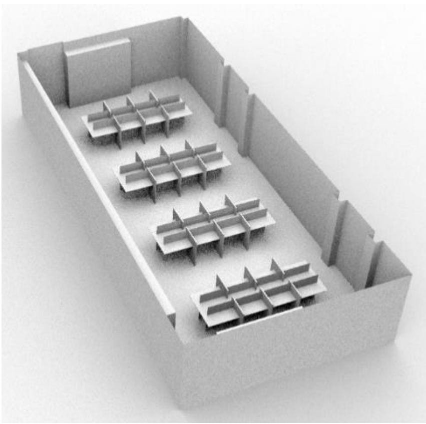
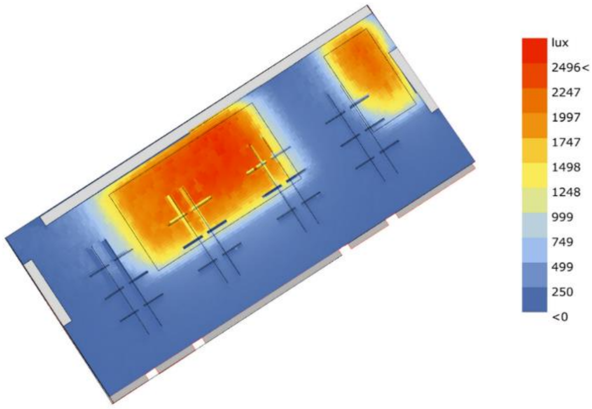


Figure 3. 5 *Schematic diagrams of the simulation process*

Table 3. 2 *Demonstration of parametric modelling and daylight simulations in the UCL Bartlett Library*

<table>
<tr><th colspan="2">Modelling</th><th>Daylight Simulations</th></tr>
<tr><td>ROOM 1</td><td></td><td>
</td></tr>
<tr><td>ROOM 2</td><td></td><td>
</td></tr>
<tr><td>ROOM 3</td><td></td><td>
</td></tr>
</table>

3.3.4.2. Spot measurements

Spot measurements were taken and used to develop and validate simulation results. For this purpose, Leica DISTO D110 Laser Distance Measurer was used to measure the size of the library. In order to run daylight simulations and generate data about daylight availability in the library, knowledge of the surface reflectances of the library's walls, floor, and furniture was also required, but no measuring equipment was available. Therefore, surface illuminance (the amount of light falling onto a given surface area) and surface luminance (the amount of light emitted, passing through or reflected from a surface) were measured using KONICA MINOLTA Illuminance meter T-10A (20014862) and KONICA MINOLTA Luminance gun meter LS 100 and the below formula (**Equation 1**) was applied to calculate the reflectance of the surfaces assuming perfectly diffusing surfaces (See the reflectance of each surface in **Appendix 1**).

Equation 1. *Calculation of reflectance value of the surfaces*

$$Luminance = Reflectance \; x \; Illuminance/\pi$$

3.3.4.3. Daylight performance metrics

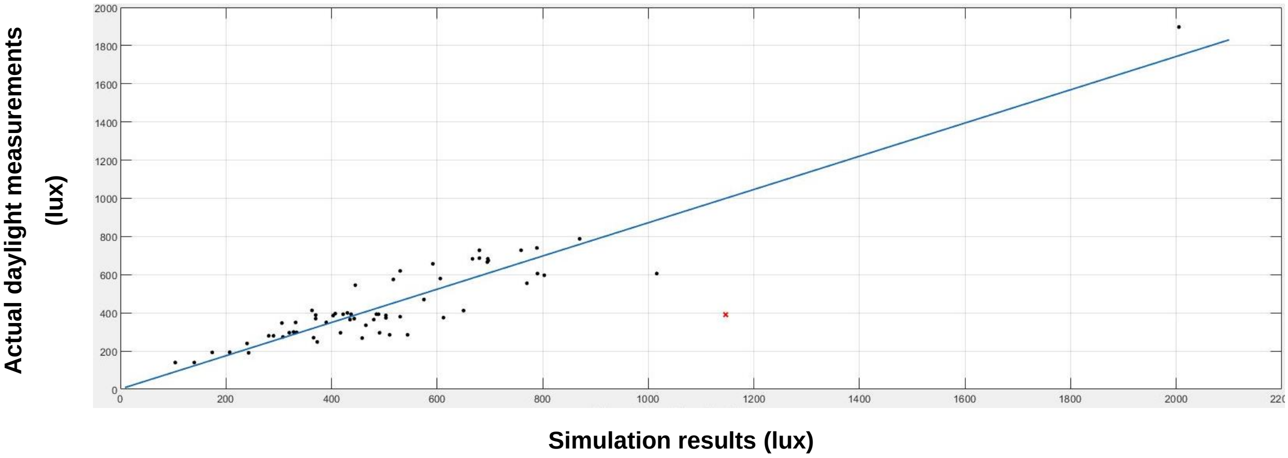
While calculating daylight availability using computer simulations, it was also necessary to specify which daylight metric to use at a given time. In this study, students were instructed to write down the date and time of the experiment in which they participated, and daylight availability was calculated based on that time. Also, the literature review findings were used to determine which daylight metrics to use in this study.

Data obtained from seat preference and subjective rating methods were evaluated based on point-in-time climate-based calculations positioned horizontally in the middle of each working desk, which has been found to have a better association with seating behaviour than other daylight metrics for predicting daylight availability [129]. Daylight boundary line drawings were assessed using DA300lx,50% (50% of the occupied time when the target illuminance of 300 lux on a horizontal plane is met by daylight) because of a more robust association with the daylight composition of space than others [106]. As a result, responses from seat preference and subjective rating methods were evaluated using point-in-time climate-based calculations, whereas daylight boundary line drawings were evaluated using Daylight Autonomy (DA).

3.3.4.4. Validation of daylight simulations

Computer simulations are increasingly being used in many contexts, and they are used to predict the dynamic behaviour of systems in response to conditions that cannot be easily applied in real life. However, the validity of the simulation outcomes is a key issue in interpreting the results. Since the simulation method results involve an acceptable amount of error arising from either unpredictable sky conditions at a given time or the incorrect input parameters in the simulation model. Therefore, it was necessary to compare daylight performance predictions obtained from computer simulations with physical measurements taken in the field in this study because it demonstrates how much simulation results correspond to actual daylight conditions.

In this study, the outcome of the daylight modellings built-in Radiance were validated under real sky conditions at a specific point, date and time. As seen in **Figure 3. 6**, a strong association between simulation results and actual daylight measurements was found ($p<0.05$, $R2 = 0.89$). It demonstrated that simulation results represent the real daylight illuminances with an acceptable error range.



$$y = 0.8708 * x + 1.334 \quad (R^2 = 0.89)$$

Figure 3. 6 *The comparison of simulation results with actual daylight measurements*

3.3.4.5. Contribution of electric light to total illuminance

The recommended lighting levels for library reading rooms are between 300 and 500 lux [62], and electric light and daylight should be considered together to achieve recommended light levels. Electric lighting was constantly on in all areas and times of the library's opening hours and times of the experiments at the UCL Bartlett Library. On the day on which the study was performed, students were exposed to electric light in addition to daylight. If the contribution of electric light was ignored, the study analysis would be inaccurate because students might not choose the same desk without electric light, particularly where daylight illuminance is insufficient in parts of the room distant from the windows and where the extra individual reading lights allow the students to carry out tasks.

Hence, the contribution of electric light to total illuminance was investigated by measuring the electric light illuminances in the middle of each desk using a Konica Minolta Illuminance meter T-10A on the 30th of November 2019 between 16:45 and 17:15 after sunset. The amount of electric light received by desks was then compared to total illuminance measurements taken during the experiment based on **Equation 2**. The illuminance values of electric light on the work planes were highly correlated with the total illuminance measurements (p=0.001). For this reason, it was assumed that all desks receive a comparable amount of electric lighting, and therefore variations between them would be due to daylight alone.

Equation 2. *Electric light contribution to total illuminance*

$$E_T(P) = E_D(P) + E_E(P)$$

$\boldsymbol{E_T(P)}$ = *total illuminance*

$\boldsymbol{E_D(P)}$ = *daylight contribution*

$\boldsymbol{E_E(P)}$ = *electric light contribution (when there is no daylight)*

3.3.5. Study procedure

Before entering the library, participants were given brief information regarding the study, and they were requested to fill out the first section of the questionnaire about the participants' personal information and backgrounds. Afterwards, they were instructed to walk through the library to carry out the following tasks:

Task 1 – Seat selection: Students were asked to choose the three best, and three worst seat locations from the seating plan of the library and the most and least liked within those categories. They were also asked to indicate the reasons for their selection to examine whether the daylight in the selected desk (best and worst) coincides with those where daylight levels were high and low, respectively, hence if the daylight component is an influential factor when deciding where to sit.

Task 2 – Subjective ratings: Students were asked to describe the amount of daylight at the best seat they have selected using a six-option scale derived from the BUS questionnaire (from very low to very high) as shown in **Figure 3. 7**. Thus, daylight availability at a specific desk was tested depending on how participants perceived it.

How do you describe the amount of daylight at **your A seat preference** (most liked one)?

Very low	Low	Below average	Above average	High	Very high
☐	☐	☐	☐	☐	☐

Figure 3. 7 *The question of the subjective ratings at the chosen best desk*

Task 3 – Daylight boundary line drawings: This unique method proposed by Handina et al. [106] was used, given its potential to represent how daylight composition can be perceived in a space. Participants were instructed to draw the “daylight boundary lines” on a paper showing the floor plan of the building whenever a significant change in light contrast (the distinction between light and dark area) was perceived when moving around the library (**Figure 3. 8**). The drawn boundary lines were then scanned and overdrawn in AutoCAD to calculate the perceived bright areas, which were assumed to indicate the perception of adequate daylight in this study. Finally, all drawings were superimposed on top of each other and evaluated based on daylight availability at a specific time.

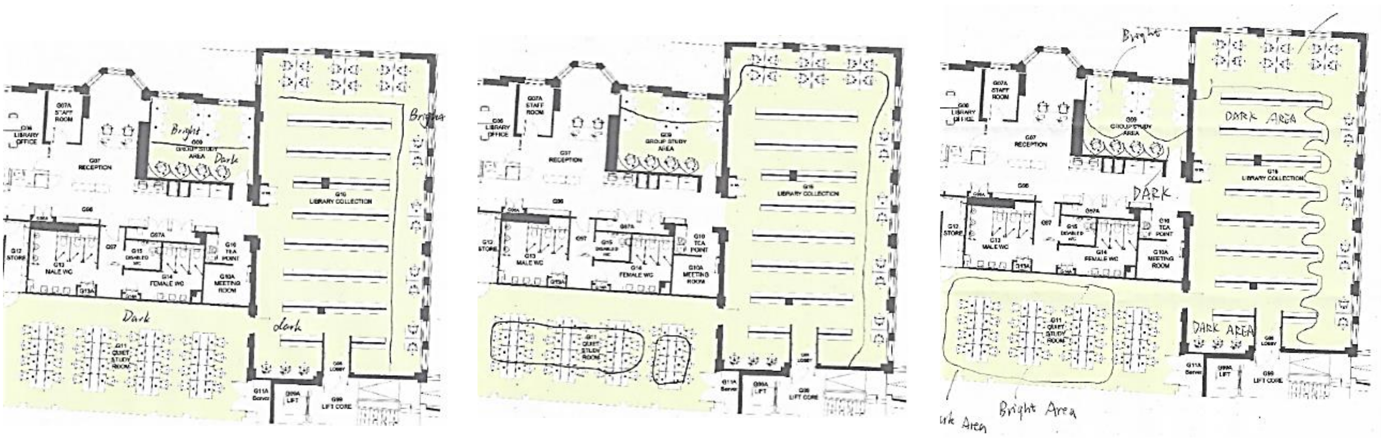


Figure 3. 8 *A few examples of participants’ drawings showing boundary lines between daylit and non-daylit spaces*

3.3.6. Questionnaire design

A questionnaire (See **Appendix 2**) was designed to include the three methods used in this study: seat preference, subjective rating, and daylight boundary line drawings. The questionnaire contained multiple-choice, Likert scale, and open-ended questions and was divided into five sections; the first two sections of the questionnaire were completed by participants before entering the library and considered information regarding **(1) demographic; gender, and age**, **(2) time spent in London (months)**. The following three sections considered a set of questions regarding the specific tasks to be conducted as part of the methods explored to measure participants' daylight perception; **(3) seating preference** and reasons for seat selection, **(4) evaluation of daylight availability** at the best seat selection, and **(5) daylight boundary line drawing** (differentiation between daylit and non-daylit spaces) The procedure order was specifically designed from open questions regarding seat preference to daylight specific questions so that they do not influence the participants' responses. Ethical approval for this study was obtained from the UCL Research Ethics Committee in November 2019.

3.3.7. Method of analysis

All statistical analyses were conducted using the software package SPSS 20.0. Univariate descriptive statistics (response frequencies, means, and standard deviations) were calculated for each variable. The data were checked for normality using analytical Kolmogorov–Smirnov/Shapiro–Wilk's tests if required. Evaluations of the data obtained from three subjective methods were carried out separately as described below:

Analysis of seat preference: Initially, compelling reasons for students' best and worst seat selections and the importance of daylight in their seat selections were considered. Secondly, daylight availability at the best seat selections was evaluated using ordinal regression. Lastly, the best and worst seat selections were evaluated on the seating map concerning other influential factors on seat selections in addition to daylight.

Analysis of subjective ratings: Subjective ratings were evaluated based on the perceived daylight conditions towards daylight availability at the best seat selection using ordinal regression.

Analysis of daylight boundary line drawings: Daylight boundary line drawings were assessed with the methodology created by Handina et al. [106]. Initially, the variation in the perceived bright areas of participants was analysed using descriptive statistic methods. Then, the statistical quartile concept was used to categorise and visualise the areas agreed by a certain number of participants as bright. Spaces were differentiated as *fully daylit* (area agreed as bright by at least 75% of the participants), *partially daylit* (area perceived as bright by at least 25%) and *non-daylit* (area perceived as bright by less than 25% of participants). Lastly, categorised areas representing the participants' overall daylight perception were overlapped with daylight availability to investigate if they correspond with each other.

3.4 Results and Discussion

3.4.1. Seat preference

3.4.1.1. Reason for seat selection

Selection of the best seats

In order to investigate the role of daylight on seat selection, students were asked to state the three best desks and the reasons for their selection. The study findings showed that daylight was the most dominant reason (36%) of all reasons given by participants when selecting the most liked desk, followed by privacy (18%), outdoor view (13%), and quietness (10%), respectively (**Table 3. 3**). These results agreed with [127] and [62] findings that daylight was the most significant reason for seat selection. In this study, other specific features of selected desks also seemed to be influential on seat selection (8%). Some specific features mentioned were wideness, proximity to the circulation route or entrance, enabling one to study individually or with friends, being at the corner or the back of the room, and access to facilities such as a computer or plug socket. Participants also mentioned reasons related to indoor conditions (7%), such as room temperature and air quality. The proximity to windows was also mentioned (8%); however, it was unclear whether it was due to daylight conditions or outdoor views.

Table 3. 3 *Participants' responses concerning the reasons for choosing the best seats*

Reason for best seat selection	*Total number of mentioned*	*A Best place*	*B Second-best*	*C Third-best*
Quietness	*10% (22)*	*10% (8)*	*9% (7)*	*10% (7)*
Daylight	***36% (81)***	*34% (28)*	*39% (29)*	*34% (24)*
Proximity to window	***8% (18)***	*9% (7)*	*5% (4)*	*10% (7)*
Outdoor view	*13% (30)*	*13% (11)*	*15% (11)*	*11% (8)*
Privacy	*18% (42)*	*21% (17)*	*21% (16)*	*13% (9)*
Desk features	*8% (18)*	*6% (5)*	*7% (5)*	*11% (8)*
Indoor conditions	*7% (16)*	*7% (6)*	*4% (3)*	*10% (7)*
Total responses	*227*	*82*	*75*	*70*

Selection of the worst seats

Following the best seat selection, participants were also asked to state the three worst desks and the reasons for their selection. As seen in **Table 3. 4**, the worst seats were associated with unsatisfactory daylight conditions (33%), and with specific desk features (14%), nonprivate environment (12%), distractive noise (11%), and lack of or unpleasant outside views (6%).

Table 3. 4 *Participants' responses concerning the reasons for choosing the worst seats*

Reason for worst seat selection	*Total number of mentioned*	*1 Worst place*	*2 Second-worst*	*3 Third-worst*
Noise	*11% (21)*	*8% (6)*	*13% (8)*	*12% (7)*
Lack of /insufficient daylight	***33% (62)***	*34% (24)*	*32% (20)*	*32% (18)*
No window	***4% (7)***	*4% (3)*	*2% (1)*	*5% (3)*
Lack of/ unpleasant outdoor view	*6% (12)*	*6% (4)*	*6% (4)*	*7% (4)*
Privacy	*12% (23)*	*16% (11)*	*11% (7)*	*9% (5)*
Desk features	*14% (26)*	*13% (9)*	*16% (10)*	*12% (7)*
Indoor conditions	*9% (18)*	*8% (6)*	*9% (6)*	*10% (6)*
Feeling cramped	*11% (21)*	*10% (7)*	*11% (7)*	*12% (7)*
Total responses	*190*	*70*	*63*	*57*

Although daylight remained one of the most dominant factors in both best and worst seat selections, the order of importance in selecting the worst seats was slightly different from those selected as best. Daylight was the most dominant reason when selecting the best desks in the library, followed by privacy, outdoor view and quietness, respectively. Nevertheless, unsatisfactory daylight conditions were stated as the most important reason for the worst seat selection, followed by specific desk features, nonprivate environment, distractive noise, and lack of or unpleasant outside views.

Even though participants seemed to agree on the reasons given when selecting the best and worst seats in general, there were a few cases where a particular desk was chosen as both worst and the best by participants due to different reasons. For instance, a group of people stated that some desks were claustrophobic and made them feel cramped. Those places were generally seats facing a wall or located in the corner of a room, restricting visual contact with other students. Some also found some corner seats close to the circulation route the worst because of the distraction possibility by passing people; however, some students indicated that sitting at the corner was a reason for the best seat selection due to “feeling isolated” from those around. Similarly, a desk facing the wall made a participant “feel cramped” opposite to another student, indicating that sitting there makes her “easy to concentrate”. These types of examples highlighted the role of individuality in seating selection because some participants described a space positively while others described it negatively. However, although seat preference varied from person to person depending on individual needs and expectations, most participants agreed that selecting a desk in the library is influenced by a satisfactory daylighting level, facing the least people, and a greenery outdoor view [136].

Seat preference in different rooms

The UCL Bartlett Library provides rooms with different layouts. While two of the rooms (Room 1 and 2) have side windows allowing access to daylight and outdoor views from the desks shared with a maximum of one person, Room 3, an open plan space, is located under a skylight without access to outdoor views but sufficient daylight levels, especially at some desks (above 1000 lux). Also, there is a space located in Room 2 that differs from the rest of the room as visually open to everyone passing through the library that does not access daylight and outdoor views but provides three hot desk computers.

Figure 3. 9 presents the seat preference configuration against the library's daylight availability as simulated and validated with spot measurements. It can be seen that most (86%) of the seats selected as the best were located in areas with high illumination, whereas most unpopular desks were located in places with poor or lack of daylight (less than 300 lux). The lighting levels were categorised based on the recommended range for library reading rooms (between 300 and 500 lux) [62]. Interestingly, two desks were regarded as both best and worst by different participants. One of them, located in Room 1, corresponds to an individual cubicle that does not have access to an outdoor view or acceptable daylight levels. The desk was selected as the worst seat by a participant because of the deficient daylight level; however, another participant preferred it because the desk was at the corner and more private than others. Another desk described as both best and worst by five participants was located near the window and in the corner of Room 2. The desk has a satisfactory level of daylight and a greenery outdoor view, which some participants positively appraised; however, others were negatively affected, given its closeness to an emergency exit and facing the people passing through the circulation route.

When the study was conducted, desks in Room 3 under the skylight had a high level of daylight (above 1000 lux). However, they were not preferred as expected, and the desks near the window in Room 2 were more popular than the desks in other rooms. Six participants stated that they do not feel comfortable in the open-plan layout of Room 3, even though it has high daylight levels, especially at some desks. They also mentioned that their screens were visible to other students and that even though it was a silent room, it was easy to get distracted due to the circulation of other students. These findings emphasised that seat preference cannot be examined only in relation to daylight, and it should be investigated together with other components reported in the study, such as privacy, outdoor view and quietness.

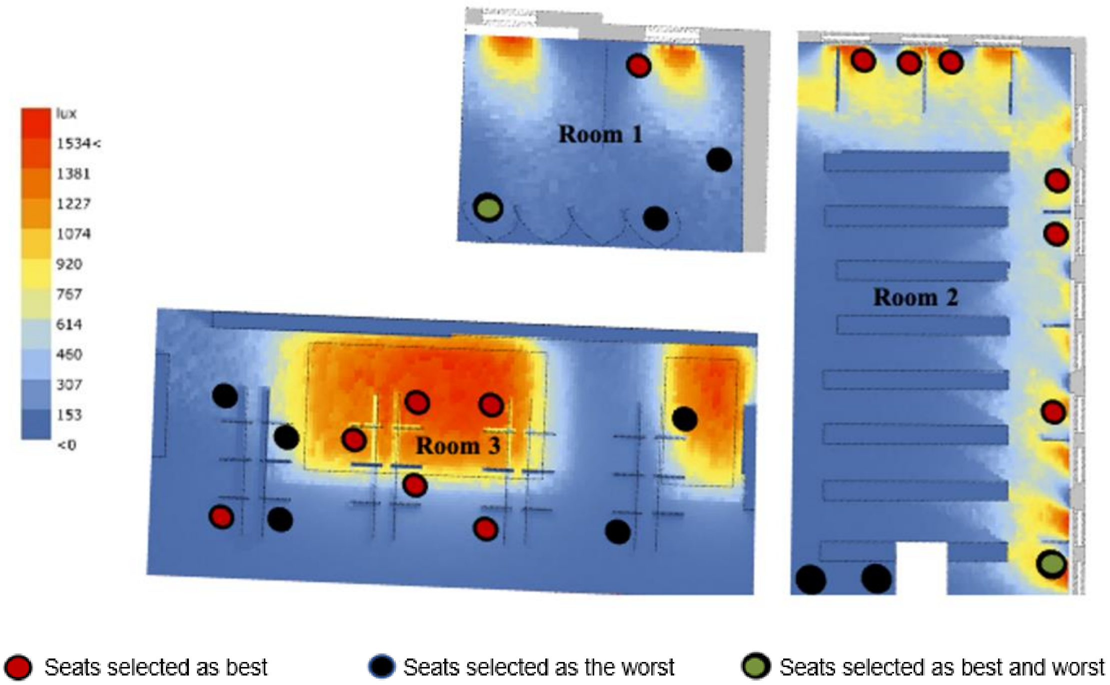


Figure 3. 9 *Best and worst seats selected by participants against daylight availability*

The role of daylight on seat selection may also vary depending on the context, sample characteristics, and the activities participants are requested to undertake. For instance, this study's results could have been different if the participants were in real need of using the space for their respective tasks (e.g., reading and writing for an assignment). In that case, privacy and quietness could have been more important than environmental components such as temperature, lighting and outdoor view. Therefore, the study design might have affected the participants' attention and evaluation of the space and desks. Nevertheless, although the role of daylight varies from study to study, the importance of daylight remains an essential factor for seat selection.

Seat preference based on seating arrangement

The individual characteristics of each desk, such as its location, orientation, and seat arrangements, also matter, as well as which room it is located in. As seen in Chapter 3, **section 3.3.3.**, the UCL Bartlett Library has rooms that provide desks with various configurations. The following paragraphs analyse and report on the best and worst seat selections, as well as the reasons for their seat selection based on individual desk characteristics.

Most students (54%) selected the best desks in **Room 2** (Zone C and D), given access to daylight and outdoor views. However, the percentage of preferred individual desks in Zone D (32%) was much higher than shared desks in Zone C (22%). Privacy could explain why these desks were preferred over others in the same room, although desks in both Zones C and D also have the same furniture features, have a similar amount of daylight availability, and have their own adjustable desk lamps in case students need an additional light source. Although desks in Zone C have a better view (church scene) and provide privacy with the use of dividers to block eye contact between students sitting oppositely, students still have to share their desks with other library users, and these desks had less demand compared to those in Zone D. Nonetheless, desks in Zone D facing the back building façade with similar features to desks in Zone C provide more privacy and less distraction, and they were in higher demand. Desks in Zone E were not selected at all as the best; because they do not have access to daylight or outdoor view and are visually open to students passing through the library.

Desks in **Room 1** were also regarded as favourable by 26% of participants. 16% of those students preferred shared desks near windows (Zone A), while others (10%) preferred individual cubicles (Zone B) without access to daylight or an outdoor view. In other words, access to an outdoor view and daylight conditions were more important in desk seating preferences than sharing a desk with someone. On the other hand, only 20% of students selected desks in **Room 3** as the best, mainly with high daylight levels. In this room, desks with high levels of daylight under the skylight (Zone F) were preferable (16%) to desks with inadequate or lack of daylight (4%) (Zone G), although all desks have the same layout and same furniture features.

Interestingly, the preferred desks with low daylight levels were located at the last line of the desks, mainly at the corners, which were described by many as more private than others. This finding shows that in the case of an open-plan space where desks do not access an outdoor view, access to daylight seems to be more important than privacy.

Hot desks in Zone E with no access to outdoor views or daylight were the most disliked by 40% of students, followed by the desks in Zone G with poor daylight conditions (32%). Despite the high daylight level in Room 3, only a few students (6%) identified desks as the most disliked in Zone F. Those desks were mainly located near the door, so anyone entering the room could see students' screens. Public feeling due to the open-plan layout and the feeling of being watched by others through the skylight were the most common reasons to dislike desks in Room 3. Participants also mentioned that their screens could be visible to other students due to seating arrangement, and even though Room 3 is a “silent room”, it is easy to become distracted due to the presence of other people sitting around.

Following Room 3, the most disliked desks were in Room 1. As the worst seat selection, most of the students (8%) pointed out the desk at the corner, next to the wall in Zone B. Only two students (4%) selected the most disliked desks in Zone A, and those desks were close to the door and had a lack of visual privacy as in Room 3. A small percentage of participants (10%) chose a desk in Room 2 as the worst seat; these were the desks with no visual privacy from passing people.

These findings showed that more illuminated spaces tend to be described as the best seat and vice versa; however, many factors need to be taken into consideration for seat selection in addition to daylight. For example, in the case of all desks with comparable furniture features and daylight availability, such as in Room 2, privacy, in other words, whether the desk allows students to sit individually, influences seating preference. In some cases, such as in Room 1, having access to an outdoor view and daylight conditions was more important than sharing a desk with someone. When there is no access to an outdoor view in an open plan space, such as Room 3, privacy and daylight appear to be important factors influencing students' seat selection; however, private desks with high daylight availability appear to be more appealing than private desks with low daylight availability. These findings demonstrated that seat selection depends on individual needs and preferences and also the specific characteristics of rooms and desks.

In support of these findings, the reasons for students' seat selections were investigated to determine whether the preferability of desks coincides with those with high daylight levels. **Figure 3. 10** shows the students' reasons for choosing the best desks. Zone E was not considered for this analysis because students did not select any desk in that zone as the best. The places with insufficient or lack of daylight, such as Zone B and Zone G, were selected mainly due to privacy and quietness. The contribution of daylight availability to the best seat selection increased from Zones A to Zones C, D, and F, corresponding to those with higher daylight levels.

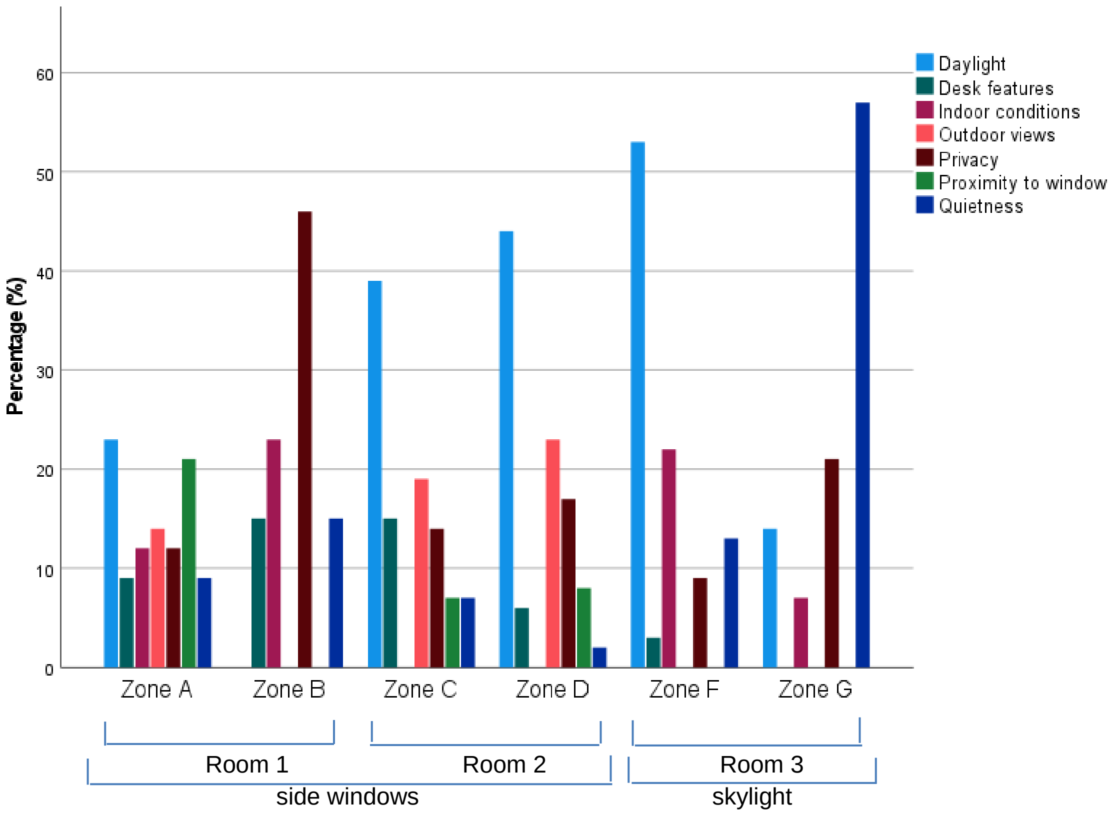


Figure 3. 10 *Students' reasons for best seat selection in different types of seating places*

Combination of reasons for seat preference

Seating that meets students' needs and preferences can promote a longer stay in the libraries and keep students motivated, influencing their emotions and learning abilities. Many disciplines have extensively discussed the influential factors on seat preference in a learning environment. It has been shown that the affecting factors arising from the physical environment that govern the decision of seat selection are daylight [92] [127], ambient temperature, type of furniture, proximity to other occupants [128], quietness, outdoor view, privacy, social interactions such as close to friends, entrance or circulation [106], students' degree of territoriality and seat arrangements [129].

Although daylight on its own seems to be a critical component for seat selection, its combination with other factors should also be considered. In this study, participants were required to state at least one, and ideally three reasons for selecting a desk. **Table 3. 5** and **Table 3. 6** present the combination of reasons for choosing the best and worst desks. As seen in **Table 3. 5**, the combination of daylight and outdoor view, and daylight and privacy are critical reasons for selecting seats. In any case, daylight maintains its importance for seat selection with the combination of outdoor view and privacy. Similarly, **Table 3. 6** showed that people avoid selecting places with insufficient daylight and a cramped environment, followed by places with an unpleasant level of daylight and outdoor views [136].

Table 3. 5 *Frequency of mentioned reasons for the best seat selections*

	Desk features	Indoor conditions	Daylight	Outdoor views	Privacy	Quietness
Desk features			2			
Indoor conditions						1
Daylight	1	1		**7**	**4**	2
Outdoor views					1	
Privacy	1	2	2	1		1
Proximity to window		1	1	1	1	
Quietness			1		1	

Table 3. 6 *Frequency of mentioned reasons for the worst seat selections*

	Insufficient Daylight	Desk features	Indoor conditions	No window	Noise	Unpleasant outdoor views	Privacy
Insufficient daylight			1	1	2	**4**	
Desk features	2			1			1
Indoor conditions							1
Feeling cramped	**6**		1			1	
Unpleasant outdoor views	1						2
Privacy	2		1	1	1		

3.4.1.2. The role of daylight availability on seat selection

Daylight availability at the best and worst seat selections

The daylight availability at the best and worst seat selections could give us an opportunity to investigate what is the role of daylight on seat selection. Therefore, students were eliminated if they mentioned daylight as a reason for their three best and worst seat selections, and these evaluations were then based on the daylight availability of each desk as determined by point-in-time climate-based calculations. For this purpose, daylight availability of the best and worst seat selections stated by students that mentioned daylight as a reason for selections was put together, and the minimum, maximum, mean values and standard deviations were analysed. As seen in **Table 3. 7,** the best seat selections of students (A, B, C) consist of desks with high illumination, and the importance of daylight decreases from the best seat selection to the third-best seat selection. Similarly, the most disliked desks (1, 2, 3) are composed of desks with a lack or insufficient level of daylight and the daylight availability increases from the worst seat selection to the third-worst seat selection. These findings demonstrate that people tend to choose more daylit spaces and avoid darker spaces during their best and worst seat selections.

Table 3. 7 *Daylight availability in the best and worst seat selections*

Daylight availability of the chosen desks (lux)	***A Best place***	***B Second-best***	***C Third-best***	***1 Worst place***	***2 Second-worst***	***3 Third-worst***
Minimum (lux)	0.00	0.34	0.34	0.00	0.00	0.00
Mean (lux)	**381.5**	**329.0**	**281.0**	**107.4**	**173.5**	**120.3**
Maximum (lux)	1395.0	1183.2	1332.8	689.8	803.6	671.1
Std deviation	399.9	276.6	287.5	184.0	260.8	195.4

Assessment of daylight availability at the best seat selection

An independent-sample t-test was carried out to check whether there was a significant difference in daylight levels at the best seats selected between participants who indicated daylight as the reason for their selection and those who did not. The findings showed that people who mentioned daylight as a reason preferred the desks with much higher daylight illuminance levels (468.5 ± 437.1 lx) than those that did not mention (174.9 ± 183 lx) ($p = .052$). It could be explained that daylight availability on a desk that meets the occupant’s needs and preferences, namely daylight expectations, usually influences their seat preference because individuals prioritizing daylight conditions tend to select desks with high illuminance levels and vice versa. This finding showed that daylight availability of the preferred desk could be used as an indicator of an individual's daylight preference and expectation.

3.4.2. Subjective ratings

The subjective rating method involves asking participants to describe the daylight conditions on a specific desk surface. This method has been utilised in many lighting studies, and most researchers have found participants' own perceptual statements compatible with actual daylight conditions. This method was applied to determine the degree to which subjective statements represent daylight availability in space and investigate whether people perceive daylight conditions in line with real measurements. The association between real and perceived daylight conditions is quite important because a deeper understanding of the possible reasons causing the variation between actual measurements and people's perceptions would help to increase occupant satisfaction in the built environment.

After selecting the best and worst seats, participants were asked to rate the daylight conditions on the work plane at the seat they had selected as the best in the library. Then, the perceived daylight conditions of the participants were evaluated towards daylight availability at the best seat selection using ordinal regression. The daylight availability at the best desks selected by participants showed that 44% of the participants (N=22) described the amount of daylight on their best desk as very high, 42% (N=21) stated that the daylight conditions were high, and 6% (N=3) as above average. In contrast, only 8% characterised the conditions as low or very low. These results support the idea that most people prefer desks with a high amount of daylight, which could be with/without consciousness [131] because the awareness of our behavioural responses to the physical environment is limited and most of our behaviour is not under our conscious control.

Although some individuals described the amount of daylight differently from actual measurements, it was assumed that the contribution of daylight to horizontal illuminance on the desk significantly affected the subjective assessment of daylight, $p = 0.002$. The correspondence between subjective ratings and daylight measurements proved that subjective rating is suitable for evaluating daylight perception. However, even if the difference between the subjective ratings and daylight conditions was minimal, inter-individual differences in perceiving daylight conditions need further investigation.

3.4.3. Perceptual daylight drawings

3.4.3.1. Variation in perceived daylight

The library's indoor daylight conditions were assessed by asking participants to draw a boundary line when they noticed a variation in light between daylit and non-daylit spaces. A few examples of participants' drawings are shown in **Figure 3. 8**. In this experiment, some participants described the daylight availability in certain areas as very high, whereas others found the daylight in the same areas low or insufficient. The overlapped drawings gathered from all participants are presented in **Figure 3. 11**, and they were then overlapped with the simulated daylight availability in **Figure 3. 12**. Participants' average perceived bright area in the library varied from ~16 to ~100 square meters (mean=40.3, SD=24.6, N=50). Perceived daylight conditions varied over an extensive range from person to person, regardless of actual daylight measurements. Therefore, aspects that can intervene and cause the discrepancy between actual daylight measurements and participants' perceptions from drawings deserve further attention.

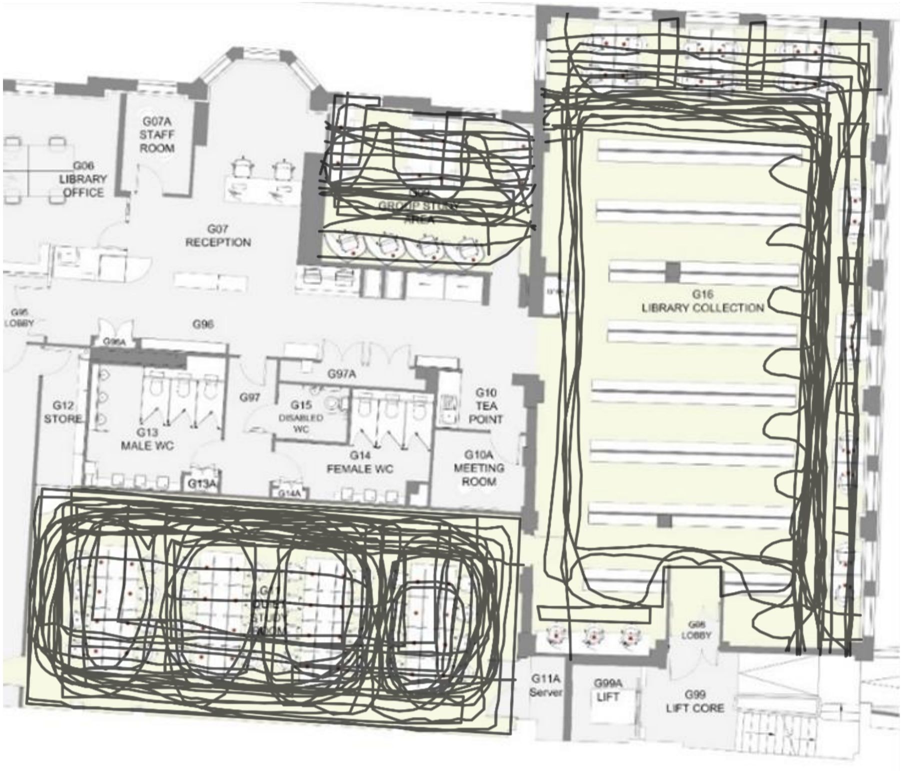


Figure 3. 11 *Daylight boundary line drawings of the participants*

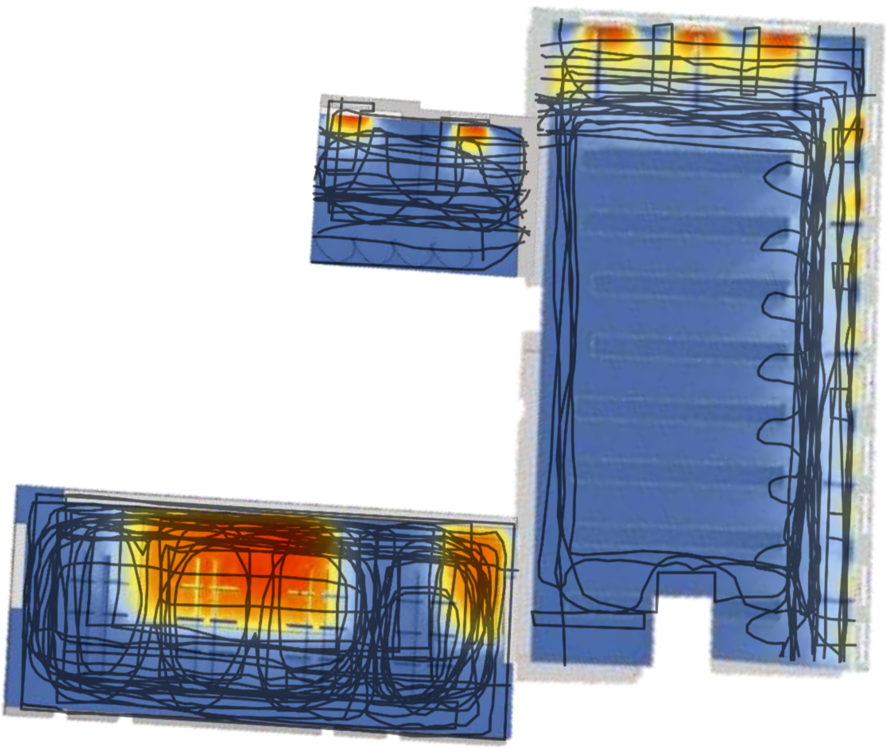
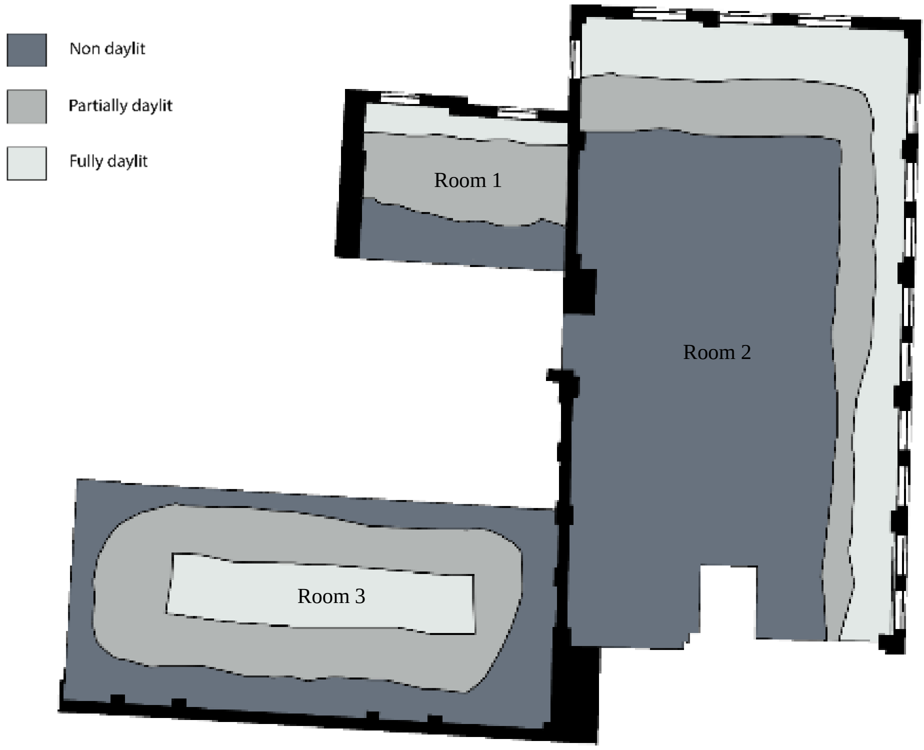


Figure 3. 12 *Comparison of drawings with daylight availability*

3.4.3.2. Comparison of daylight availability with the overall perception

In order to categorise and visualise the areas agreed by a certain number of participants as bright, the overall perception of daylight composition within each room was evaluated using the statistical quartile concept. Spaces were differentiated as fully daylit (perceived as bright by at least 75% of participants), partially daylit (perceived as bright by at least 25% of participants), and non-daylit (area perceived as bright by less than 25% of participants) (**Figure 3. 13**). Despite the inter-individual differences in the participants' perceived daylight conditions from drawings, there are still apparent areas in the centre of rooms 2 and 3 that all participants agreed to be the dimmest and brightest, respectively.



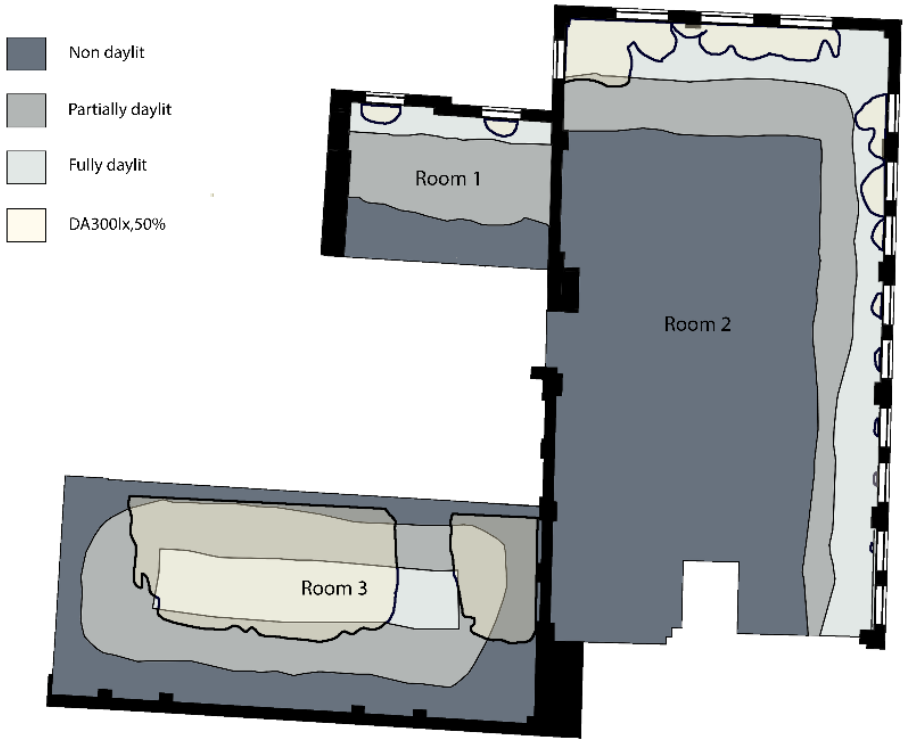


Figure 3. 13 *Overall perceived area of participants (above), Comparison of the overall daylight perception with percentage of the area enclosed with the contour line of DA300lx,50%*

The participants' overall daylight perception was overlapped with daylight availability in the library to determine the difference between perceived daylight availability from drawings and actual daylight measurements. Handina et al. [106] found that the most compatible metric to evaluate boundary line drawings concerning daylight availability in space is DA300lx,50% which is a daylight availability metric that corresponds to 50% of the occupied time when the target illuminance of 300 lux on a horizontal plane is met by daylight.

As seen in **Figure 3. 13**, only in Room 3, the percentage of the area enclosed with the contour line of DA300lx,50% (41.3%), corresponds to some extent to the partially daylit area (45.1%). However, the percentage of DA300lx,50%, was not close to the fully daylit areas in the other two rooms. This method seems somewhat to explain the tendency in daylight perception of a group of people, despite the noticeable inter-individual differences in the daylight boundary line drawings. It could help compare the daylight perception of a particular group of people, such as the perception of people living in different latitudes. However, space characteristics such as room size, window type and size, and seat configuration could explain the variation in participants' perceptional drawings. Also, as seen, the degree of agreement in the participants' perceived bright areas varied. Even though perceived bright areas varied from person to person in Rooms 2 and 3, the agreed daylit space was more noticeable. Perceived bright areas in Room 1 varied in a wide range, and there was no agreement in the participants' perceptions. These findings agree with Handina et al.'s [106] work, where a noticeable difference was found in the subjective daylight evaluations between small and large spaces. Overall, these findings indicate that this method could be used to compare the overall daylight perception of a particular group of people; however, it needs further investigation for the individual assessment of subjective daylight.

3.4.4. Initial findings on daylight perception and cultural background

This chapter aimed to review the methods previously used to assess daylight perception and establish a methodology for assessing daylight perception in the context of cultural background. As presented previously in **CHAPTER 3,** seating preference and subjective ratings seem as suitable methods for evaluating the daylight perception of individuals. Therefore, as a part of cultural background in the lit environment, the contribution of ethnic background and time spent in a specific environment to the participants' responses was analyzed considering the findings from seat preference and subjective rating methods.

The results from the seat preference method showed that when selecting the best seats, the leading reason for 48.5% of Asian participants was daylight, followed by privacy (15.2%), quietness (6.1%) and indoor conditions (6.1%). On the other hand, 33.4% of White participants selected their favourite desks considering daylight as a priority. Subjective rating method results also showed that Asian participants described daylight conditions on the best-selected desks as equal or lower than actual measurements. In contrast, White participants described daylight conditions as similar to or higher than actual daylight conditions. This finding shows similarity with Lee and Kim's [137] study, which showed that Asian people felt more comfortable than Caucasians with high glare levels of luminance.

In terms of time spent in London, study findings showed that participants that had been in London for longer periods gave less weight to daylight while selecting a seat than students that arrived a couple of months before the study. Four students born and raised in London preferred desks with significantly less daylight than non-Londoners. In parallel with their seating preferences, students who had spent more time in London described the daylight conditions at the best desk as more acceptable. Acclimatisation to daylight conditions over time could affect subjective daylight evaluations and explain this finding, just as shown by Martin et al. [138]. However, participants' daily routine, how long they are exposed to outdoor daylight conditions and in which timeframe also matter in addition to the daylight availability of the city. Together these findings show that there could be an association between cultural background and subjective daylight evaluations; however, it needs further investigation with a large sample size of participants considering all cultural background components.

3.4.5. Limitations and future work

- The presented study in this chapter was limited to a particular place and a particular group of people at a given point in time. The small sample size was another limitation that did not allow the generalisation of the findings.

- The role of daylight on seat selection may vary depending on the context, sample characteristics, and the activities participants are requested to undertake. Study results could have been different if the participants were in real need of using the space for their respective studies (e.g., reading and writing for an assignment). In that case, privacy and quietness could have been more important than natural environment components such as temperature, lighting and outdoor view. Since a degree of privacy [139] and a quiet environment [140] are the most critical components, especially during exam periods, helping students improve concentration. Therefore, the study design might have affected the participants' natural environmental attention and evaluation of the space and desks.

- Even if the difference between the subjective ratings and daylight conditions was minimal, the reasons for perceiving daylight conditions different from other individuals need further investigation, and inter-individual differences should be examined deeply in further studies.

- The use of drawings to measure participants' perceptions, such as the daylight boundary line method, has some limitations because it involves simultaneous cognitive and motor processing. Therefore, most people make errors while trying to produce a representation of a scene because of their drawing proficiency [140], and it is suggested that when a drawing is used as a research method, it should entail participants' drawing and talking or drawing and writing to interpret the meaning embedded in their drawings.

- The impact of cultural background on daylight perception was evaluated considering only ethnic background and time spent in London. However, cultural background in the lit environment comprises many aspects. Further analysis is needed considering the luminance environment where people used to live and individual lifestyle daily routines.

- Electric lighting was constantly on in all areas and times of the library's opening hours and times of the experiments at the UCL Bartlett Library. In this study, students' daylight perception had to be assessed in a real-world library setting while they were exposed to both daylight and electric light. However, their perception may differ if the students were only exposed to daylight. As a result, additional research into the impact of solely daylight on students' daylight perception, seat selection, and evaluation of daylight conditions is recommended.

3.5 Summary

Daylighting is an essential component of the indoor environment that can greatly influence the occupants' comfort and well-being. For assessing the daylighting quality, photometric measurements on their own do not wholly represent the subjective aspect of the lighting environment; therefore, more attention should be paid to how participants perceive the same daylight conditions and which method can predict the daylight perception of the participants much better. This chapter has evaluated the applicability of three methods chosen from those previously presented methods (**Table 2. 2**) to identify inter-individual differences in students' daylight perception due to cultural background. In lighting studies, culture represents the many aspects of individuals' characteristics and the climatic and indoor conditions people have experienced. Hence, people from different cultural backgrounds might have different expectations of the lit environment. This knowledge could be used to investigate how users interact with the building and develop strategies to reduce unnecessary electricity consumption in addition to contributing to human health and well-being.

This chapter showed that subjective ratings, the amount of daylight described by participants, coincide with the daylight availability on specific surfaces. However, there remains a slight difference between participants' statements and actual daylight conditions. The reasons why daylight conditions are perceived differently by participants need further investigation. The findings from the seat preference method showed that daylight was the most dominant reason when selecting the best desks in the library, followed by privacy, outdoor view and quietness, respectively. Although the reasons for seat selection varied, the majority of the participants agreed on particular reasons; satisfactory daylighting level, facing the least number of people, and a greenery outdoor view. This study also showed that the perceived daylight conditions obtained from the daylight boundary line method varied extensively from person to person, regardless of actual daylight measurements. Therefore, aspects that can intervene and cause the discrepancy between actual daylight measurements and participants' drawings deserve further attention. Initial results from the developed method demonstrated that there could be an association between cultural background and subjective daylight evaluations; however, it needs further investigation with a large sample size of participants considering all cultural background components.

Together these findings showed that subjective rating and seat preference methods could be used to evaluate daylight perception. Although daylight availability corresponds better with subjective statements, collecting participants' subjective responses would not always be possible, especially in large-scale studies. Therefore, the combination of subjective rating and seat preference methods is suggested as appropriate methods for assessing daylight perception. Future research should also consider the impact of other environmental parameters on seat preference and how they relate to lighting conditions to improve occupant satisfaction. The interaction between any parameter and seating choice should not be examined in isolation; other aspects, such as privacy, outdoor view and quietness, should also be considered. Inter-individual differences in daylight perception are also worth investigating further.

CHAPTER 4: Investigation of the role of daylight availability on seat preference

4.1 Introduction

Academic libraries should play a significant role in students' learning process by providing an environment that enhances their learning experience and contributes to their academic and intellectual development. Seating that meets the needs and preferences of students can promote a longer stay in the libraries and keep students motivated, which in turn influences their emotions and learning abilities. Studies regarding seat preference in learning environments have primarily focused on interior elements, such as the impact of territory, colours and furniture on students' seat selection [119], and existing knowledge on the interaction between daylighting and seating behaviour remains limited and needs to be investigated more deeply [129]. Therefore, the degree of satisfaction with daylight conditions could significantly impact individuals' mood, behaviour and cognitive performance.

Although most participants stated a satisfactory daylighting level as the most dominant reason when selecting the best desks in **CHAPTER 3**, it was limited to the choice of a group of people at a given point in time. Therefore, a further long-term analysis was needed to confirm the role of daylight in seating selection. This chapter aims to understand what types of desks are in higher demand in a library and investigate whether daylight has a significant impact on student seating selection, providing that students have a free choice of seat location, in order to develop some strategies to improve students' satisfaction with space and reduce building energy consumption. For this aim, occupancy data of the UCL Bartlett library acquired from motion sensors located underneath each desk was used to assess occupancy, which was then compared to characteristics of space, including daylight availability. The detailed information in the literature regarding the role of daylight availability on seat preference, assessment methods of seating preference in the learning environment and the method of procedure are reported in the following sections.

4.2 Literature review

4.2.1 The role of occupant behaviour in the built environment

Occupant behaviour has been regarded as one of the critical factors that might cause a gap between the predicted energy use during the design stage of a building and energy use in the operation stage [124]. The performance gap between how designers predict occupant behaviour and how they actually operate sometimes could vary up to 300% difference. Since energy simulation tools used for predicting energy utilisation of buildings mainly consider the climatic data and physical/ thermal properties of building elements rather than occupant behaviour. Occupant behaviour is regarded as fixed and scheduled patterns; therefore, predictions always do not represent realistic human behaviour [141]. However, the unexpected occupancy behaviour as one of the significant factors impacting energy use is responsible for 64% of the difference between the predicted and actual energy consumption of buildings [142]. It has several direct and indirect factors that may have an influence on the way that occupants consume energy. For instance, occupant behaviours in terms of energy use in the built environment could be influenced by external sources such as climatic conditions, type of building and building features and indoor physical environment, as well as by internal sources such as biological and psychological conditions, comfort level and expectations, values, social interactions, gender and age [124].

Understanding the role of occupant behaviour in the built environment and investigating the occupants' interactions with the indoor environment could help to improve occupants' satisfaction [121] as well as energy efficiency in a building [122] [123]. For instance, understanding the factors influencing the occupants' interaction with electric lighting (patterns of turning artificial lights on and off) could help minimize the performance gap between predicted and operational lighting consumption as well as maintain the occupants' satisfaction with the built environment [143]. Research conducted in Korean office buildings with the application of automatic dimming control for lighting with a design illuminance of occupants’ expectations and usage habits helped to reduce lighting energy consumption by up to 43% [23]. However, due to the complexity and variety in the factors of potential influence on occupant behaviours such as lifestyle, demography, economy, interaction with building features and equipment, predicting beforehand building occupancy behaviour and buildings’ energy use could become problematic in general and on occupants in particular [125]. Therefore, further research into the factors affecting occupant behaviour is needed.

4.2.2 Influencing factors when choosing a space in the learning environment

The expectation of occupants and their behaviour in the built environment could vary depending on the building type, building design features, climatic conditions, type of activity [141], and people’s personalities [144]. Understanding occupants' behaviour and their interactions with the indoor environment could provide insights into how to improve occupants’ satisfaction [121] and the energy efficiency of a building [122] [123]. For instance, understanding the reasons behind selecting a particular seat in an environment could help develop strategies to improve occupants’ satisfaction and maximise the benefit of an environment such as a library that has an essential role in enhancing students’ cognitive abilities and achievements.

The seat selection process results from the individuals’ prior experiences in a space or a deliberate choice among alternatives while entering the space [130], regardless of whether deciding consciously or unconsciously [131]. Seating selection differs for individuals familiar or unfamiliar with a space’s physical settings [62]. The human response to the physical environment is strongly subject to prior experiences [132]. For example, library users could repeatedly choose the same seat depending on prior experiences, whereas first-comers need to rely on external sources such as existing lighting conditions, noise levels, etc. This situation may apply not only to previous experiences in the same library, but also to seating selection of students in similar setups. The availability of seats at a particular time could also influence seat selection; individuals who arrive earlier at the library have more chances to select a seat than those arriving later. Individual differences, namely arousal, motivation, and expectation, also matter in human behaviour [132], influencing the decision-making process. All these factors considered together could make a difference in individuals' seat preference behaviour.

Linking the seating behaviour of individuals with a particular stimulus in the physical environment is quite difficult because individuals are exposed to multiple sources of information during the seat selection process. The behavioural response to a physical stimulus in an environment is not directly associated with its magnitude, but with the interaction of the people and the environment, they are exposed to [132].

The factors influencing seating behaviour in the learning environment have been defined as ambient temperature, type of furniture, proximity to other occupants [127], quietness, outdoor view, privacy, social interactions such as close to friends, entrance or circulation [105], daylight [90] [126], students' degree of territoriality and seat arrangements [128]. It is also known that when choosing a space, individuals are likely to value a few specific variables rather than equally evaluate each environmental variable [62]. Therefore, it is impossible to associate students' seating behaviour with only one environmental variable. However, some factors are more dominant in the decision process of the students, and it is necessary to understand whether daylight availability is one of those factors influencing students' seating preference predominately. The literature shows that the impact of daylight on seating behaviour is also affected by variations in other factors that influence the decision-making process, and the role of daylight in seat selection remains hidden behind them [42]. The underlying processes of seating behaviour within a specific physical environment have not been completely understood yet. Understanding the interaction between physical environment and seating behaviour of students is important to design functional and comfortable learning environment.

4.2.3 The role of daylight availability on seating selection

An individual's spatial orientation relies on the interpretation of changing retinal images and updating this information whilst walking through a space [145]. The received visual information with auditory and tactile senses is used to decide on location, position and movement [62]. Therefore, as a part of the dominant source of sensory information (vision), daylight is regarded as an essential component for the spatial orientation of an individual. It gives individuals a sense of place with “the changing intensity and direction of illumination over time” [62] and potentially influences their spatial orientation within an environment [132] [127]. The luminous environment could impact individuals’ decision-making process in remaining at the same location or moving elsewhere. In the case of changing the location and, ultimately, the luminous environment, individuals may develop a sense of awareness of the luminous similarity or contrast (higher or lower amount of illumination) with other spaces. In other words, they put spaces in luminous order while they make a seat selection [146].

The type of task to be also performed matters for the importance of daylight on seat selection. For example, visual tasks requiring greater attention, such as reading a book, may influence individuals to choose particular locations with mostly higher daylight levels [146] [147]. However, in some situations, people may need a place to focus on what they are reading with less awareness of sensory information arising from their external environment [147]. Especially during exam periods, privacy and quietness are more critical for students [139] [140] than external environment sources like daylight levels. In addition to individuals who positively appraised daylight conditions, avoiding visual discomfort could also be another reason for seat selection for others. For instance, individuals may choose spaces away from direct sunlight to avoid potential visual discomfort through glare [62].

4.2.4 The assessment methods of seating preference

In order to assess the factors influencing occupants' seating preferences, it is necessary to review the methods for assessing seating preference in the literature. In the literature, seating behaviour studies have been conducted in either real-world or laboratory settings. In laboratory studies, occupants' behaviours and preferences could be artificial and unrepresentative since it is difficult to reproduce the dynamic social context in real-world situations. Also, participants are aware of being observed, which may influence their seating choices. In real-world studies, on the other hand, it is impossible to change the environment to control variables or interfere with the behaviour of the people being observed. The real-world approach prevents people from being influenced by the experimental set-up and behaving differently, as long as they do not know they are being monitored. Thus, real-world studies improve the reliability of the observations [89] [62].

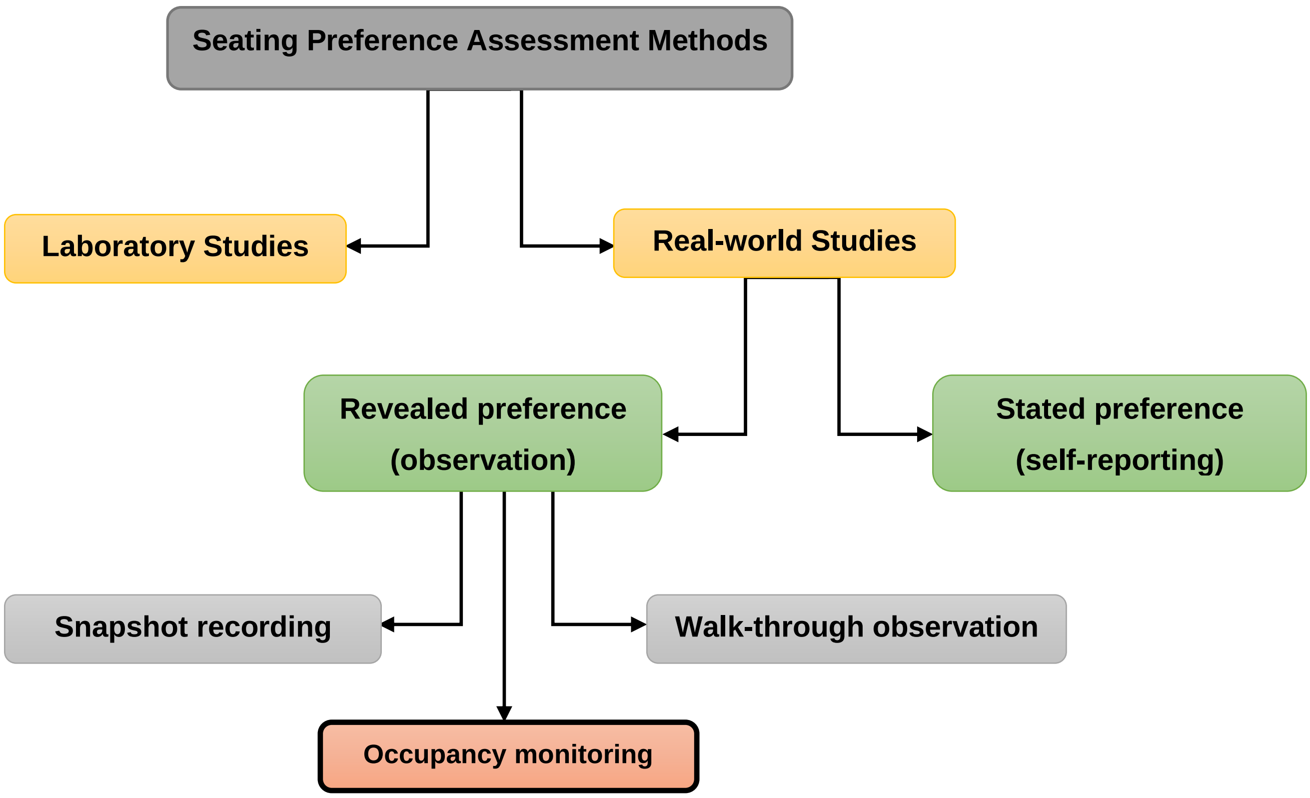


Figure 4. 1 *Methods for the assessment of seating behaviour in the literature*

As seen in **Figure 4. 1**, seating behaviours in real-world studies have been monitored either from direct observation of the subjects' behaviour (*revealed preference*) or self-reported behaviour (*stated preference*). ***The stated preference method*** depends on the individuals' expressions regarding their perceptions and expectations of the seating places using ***surveys and interviews.*** The revealed preference method differs from the stated preference with the actual behaviour observation rather than stated perceptions or intended behaviours. Although the revealed preference methods provide insight into the general seating behaviour pattern, they do not involve the subjective aspect of choosing a space. However, it is usually challenging to generalise the findings using the stated preference methods because they generally can reach a limited number of participants' subjective expressions. Furthermore, those perceptional expressions can not always represent the intended behaviours because most human behaviour is not under conscious control [131]. Thus, the assessment of seating preference should benefit from a combination of revealed and stated preference methods altogether to assess the seating behaviour of the people in a space.

The revealed preference method comprises a systematic observation of actual behaviour against measured physical settings in which the behaviours occur. It has three approaches; ***recording a snapshot, walk-through observation, and occupancy monitoring.*** The former approach involves monitoring and recording human behaviour at specific intervals. The latter represents the recordings of people's behaviour, such as observing them while choosing a seat, monitoring the preferred path while moving through space, and noting their activity while sitting. Seating behaviour is also observed using the occupancy monitoring method, which comprises a systematical analysis of each seat's utilisation at specific intervals.

The occupancy monitoring studies in libraries generally have two approaches. One of those approaches is examining the seating and space usage, interpreting the findings and proposing new furnishings, interior design or renovations [148] [149]. The latter approach is the development of models to predict occupant behaviour and schedule prediction based on the actual behaviour occupancy data obtained from different kinds of sensors [150]. The primary goal of the studies measuring the occupancy pattern in libraries using occupancy sensors is to provide students with more efficient library use. For this aim, some researchers have assessed the occupancy patterns in the libraries over several months to evaluate the efficiency of library usage [151]. Some have compared the accuracy of different sensor types to determine the most corresponding ones with occupancy of the seat configurations [152], and others have created models to predict future occupancy using the information obtained from the sensors [153].

4.2.5 Occupancy monitoring sensors

As previously mentioned, the occupancy measurement in the built environment is usually conducted with manual counting and questionnaires. However, these methods usually require verification with other ways to obtain representative data of actual occupied conditions in space. They also need a lot of labour force and considerable time to collect the occupancy information. The working load also could be extremely heavy when the recording is required for a long time. The advances in sensor technology allow researchers to replace the head counting method at specific intervals with different kinds of sensors to detect whether a seat is occupied. Researchers have mainly benefitted from these occupancy sensors; passive infrared (PIR), ultrasonic, sound, light-switch, carbon dioxide, and image sensors [154].

One of the most widely used sensors is the PIR sensor, a motion detector type that defines an area's occupancy status using the infrared (IR) light radiating from occupants. They represent the occupancy status of a place with an output value of zero or one describing “unoccupied” or “occupied”, respectively. These sensors respond when they detect a change in the temperature, and they require the constant motion of the occupants to function effectively [155]. Ultrasonic sensors can also catch the occupants’ presence using the echo intensity and transmitted signals. Their working principle depends on emitting the ultrasonic sound waves from the sensor to the environment and receiving the reflected sound energy back to the sensor from the environment. If the reflected sound energy has a different wavelength from the sent one, then that space is regarded as occupied because sound waves switch wavelength after reflection from a moving object. However, these sensors occasionally may give false ON due to the air turbulence caused by HVAC systems [154] [155]. The study represented in this chapter is based on the data obtained from PIR sensors at UCL libraries.

The sound sensors measure and evaluate the audible sound waves of occupants using a microphone or other audio detector to detect their presence and locations in the room. These sensors also provide a binary output value to detect the occupant's presence, like PIR and ultrasonic sensors. However, they require occupants to make continuous sounds, and such sound sensors could consider some non-human sound waves as false ON. In some cases, they could be applied along with PIR sensors to complement each other [154] [155]. Light switch sensors detect occupant movement and control the lighting switch. They have a binary output like other sensors, and they consider that space is occupied when the light is switched on due to the occupant's movement. These switch sensors rarely give false ON because they are triggered by people walking through the space, even if it is not occupied. In a few cases, they could provide a false OFF output if the occupant remains overly static in the space [156].

Besides, carbon dioxide sensors are used to measure indoor and outdoor air carbon dioxide concentration to estimate the number of people who occupied the room [157]. However, the exhaled carbon dioxide diffusion to the air takes some time. Therefore, these sensors generally give a time lag, and it causes a problem in estimating the number of people at a particular time [154]. The working principle of image sensors is based on capturing human movement through the sixteen-node sensor network of cameras [158]. However, the system could represent only 80% of the actual occupancy in a space [154].

4.2.6 Application of occupancy monitoring sensors to the libraries

Researchers who prefer to monitor the occupancy pattern of the libraries and the time duration that each seat is occupied usually count the occupancy in an interval time manually. This method was limited to the restricted time period because researchers usually could have observed the occupants' seating behaviours for only a week or two weeks within different seasons [64]. Some researchers occasionally utilize the datasets obtained from motion sensors attached to desks and desk stations to monitor the occupancy of the library. Usually, motion sensors have been used because these sensors give more accurate results than other sensors to detect the occupancy in a particular place. A few researchers [159] also have utilised occupancy sensors to help design energy-efficient buildings because understanding the link between occupancy patterns and energy usage is quite important. They have demonstrated that the total energy consumption of the library could be reduced by 26.1% when the opening hours are rearranged depending on the hours when a room is primarily vacant or occupied by a few people. They have also highlighted that considerable energy consumption in the libraries results from lighting energy use, which could significantly (71%) be reduced using the in-depth analysis of occupancy patterns.

Despite the advantages of sensor technology, occupancy monitoring sensors have not been used frequently because this method requires a sufficient number of sensor devices for each seat or at least each cluster seating where the observation will be done. Even the researchers who utilized sensors for occupancy monitoring could install sensors to specific seating clusters and observe only a limited part of the library due to the lack of sufficient sensors for monitoring each seat. Hence, a long-term analysis of each seat in a library associated with indoor conditions, particularly daylight availability, could not be conducted yet. Therefore, this chapter has focused on the long-term occupancy of each seat at the Bartlett Library obtained from motion sensors to investigate if daylight availability encourages students to choose seats where a high daylight level exists.

4.2.7 The significance of the study

The building occupant behaviour, usage and maintenance of the buildings need further attention to increase the satisfaction of the occupants as well as avoid unnecessary energy consumption. The unexpected occupancy behaviour is one of the significant factors impacting energy use because it is responsible for 64% of the difference between the predicted and actual energy consumption of buildings [142].

It is crucial for UCL's professional services teams to ensure that study spaces at UCL are both sufficient and well utilised to maintain students' satisfaction with the library environment and avoid high energy expenditure. Below bar chart (**Figure 4. 2**) visualizes the average monthly occupancy rate and electricity consumption of the Bartlett Library between 2018 and 2019. Electricity consumption data was gathered from UCL live energy data platform. It has been shown that the occupancy rate of the Bartlett Library is highly dependent on the term dates. However, compared with the current electricity consumption plan, it demonstrates that the energy consumption is not proportional to the actual occupancy, which could result in much energy and money wasting [122] [123].

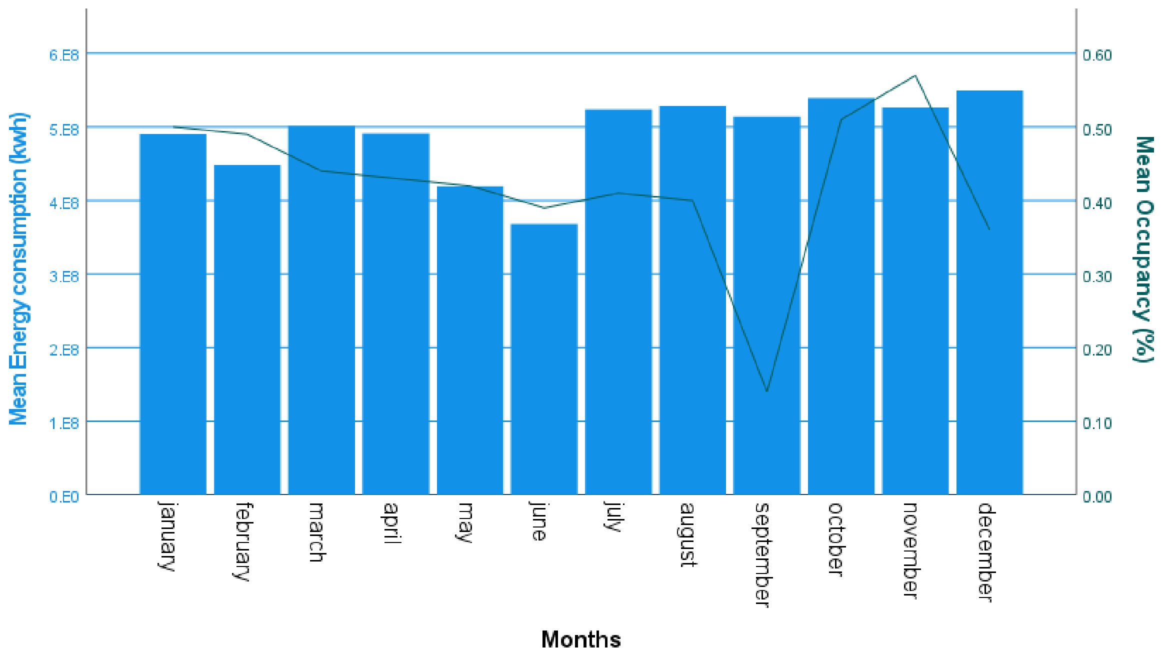


Figure 4. 2 *Comparison of energy consumption and occupancy rate at the Bartlett Library*

Although there is no way to disaggregate the energy consumption for heating or cooling the space, ventilation and lighting using the UCL libraries' electricity consumption data, it is known that lighting accounts for a considerable amount of energy used in library buildings interrelated with the cooling and heating loads. For this reason, assessing occupancy patterns depending on the lighting availability could be very beneficial for UCL Estate to maintain students to use the libraries more efficiently. In this way, managers could have a chance to investigate the reasons behind lowly-utilised desks and spaces. They could set up a new lighting control that matches actual building occupancy more closely than current settings, and even some rooms could be closed during the lowly utilised period to reduce unnecessary energy consumption in UCL libraries.

4.3 Methodological approach

4.3.1 General approach

The previous chapter (**CHAPTER 3**) aimed to identify the most suitable methods to assess daylight perception of a large number of people to investigate the cultural background impact on daylight perception and concluded that seat preference seems like one of the suitable methods for assessing daylight perception. It demonstrated that people mostly tend to select desks with a high amount of daylight. However, lighting conditions constitute only a part of the compelling reasons for the best and worst seat selections, and other factors also need to be considered, such as privacy, noise level and outdoor view in addition to daylight conditions.

Therefore, a further study was needed to reconfirm the previous findings on the role of daylight availability on students' seat selection, not limiting the observation to a specific time duration but expanding it to a long period of time. Unlike researchers that previously monitored the occupancy pattern in the libraries for a short period of time, this study monitored the occupancy using motion sensors located underneath each desk in the Bartlett Library for the entire year. The collected data was utilized to understand how the study spaces are used, what type of spaces are most in-demand, and the relationship between seat occupancy and daylight availability.

4.3.2 Field site

This study was conducted based on the utilization data of each desk at the UCL Bartlett library and daylight availability. The UCL Bartlett Library is located on the ground floor of a six-storey building. The features of the library were described previously in Chapter 3, **section 3.3.3**. The library comprises three main study areas with different layouts and lighting designs. Room 1 has eight shared desks and four individual cubicles, Room 2 has twelve shared desks and eleven individual desks, and Room 3 has thirty-two shared desks. Regarding daylight, Room 1 has two north-facing side windows, and Room 2 has several side windows facing north and east orientations. Room 3 is an open-plan space with two skylights.

4.3.3 Occupancy monitoring data at the UCL libraries

The utilization of seats in each UCL library has been monitored and recorded on a 10-minute basis since 2017 [160]. The purpose of monitoring the occupancy of 4,000 seats is to provide students real-time spatial distribution of available desks via an app called ‘UCL Go!’. The app provides students with real-time information on study space availability at UCL libraries, as well as information on when the libraries are busiest during the day and which libraries have the most availability. It enables students to find available space quickly and saves their time, especially during the highly utilised periods of the libraries, such as exam periods, when scheduling a visit to the library, to avoid crowding in advance. It also allows students to choose an adequate study space according to their needs and expectations, which will considerably impact students' academic performance [161].

Students had access to an information page (**Figure 4. 3**) indicating not only the availability of the library but also which desks were available at the time when they logged into the UCL Go! Application to check the availability of desks in the libraries. However, the Coronavirus Pandemic (COVID-19) and associated restrictions required all students to only use the desk they had reserved and to leave space between themselves by restricting the available desk options. **Figure 4. 4** illustrates how the current system only enables students to see how many desks are available on each floor and requires them to reserve a desk without giving them the option to choose in advance. Therefore, this study considered the time period before the pandemic when students could freely choose seats because of the restrictions on students' seat selection after Covid-19.

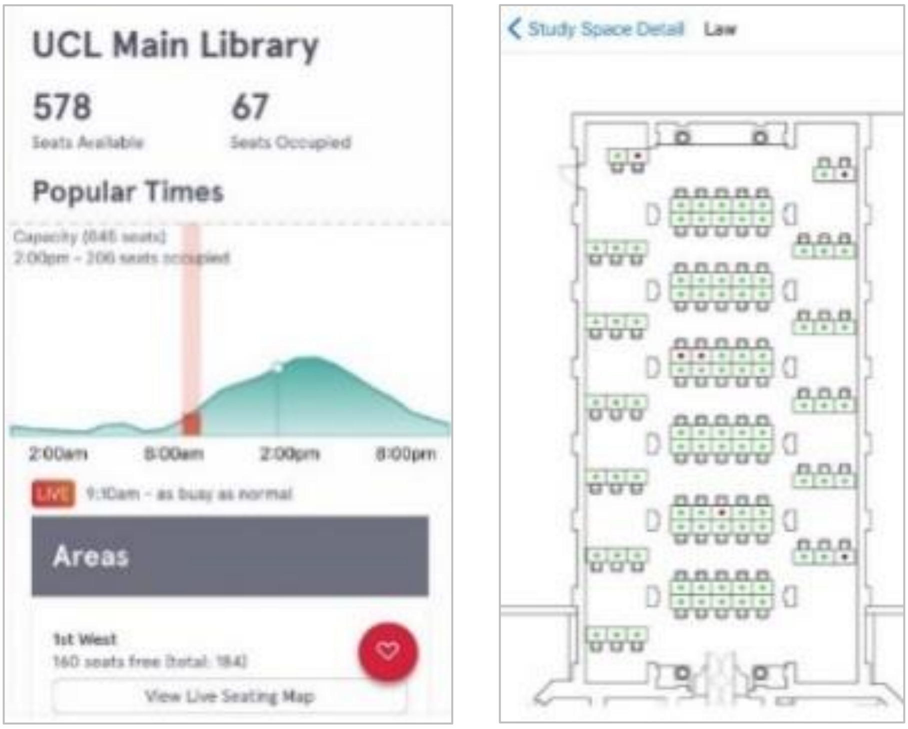


Figure 4. 3 *The previous version of the space availability information on the UCL Go! app*

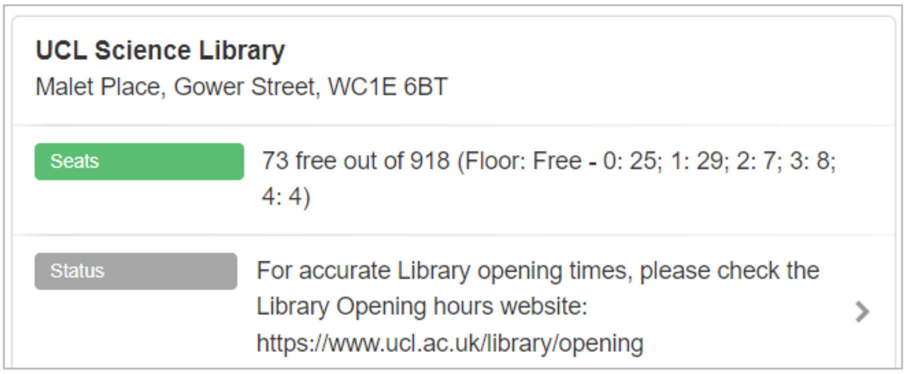


Figure 4. 4 *The updated version of the space availability information on the UCL Go! app after COVID-19 restrictions*

Occupancy data is obtained from PIR sensor boxes with infrared technology attached to each desk's base, detecting if the desk is available. The information regarding whether the particular desk is occupied at a specific time is sent to OccupEye Cloud and is plotted using a range of red and green colours that indicate for what percentage (%) of the desks have been occupied at a specific time duration (**Figure 4. 5**). Sensors send the occupancy information to the OccupEye Cloud in a 10-minute interval indicating if the desk is available or not. Then the percentage of occupancy is calculated on how frequent that desk was utilized in the desired time interval. The collected data can be extracted at the desired time intervals on a daily, weekly, monthly and annual basis.

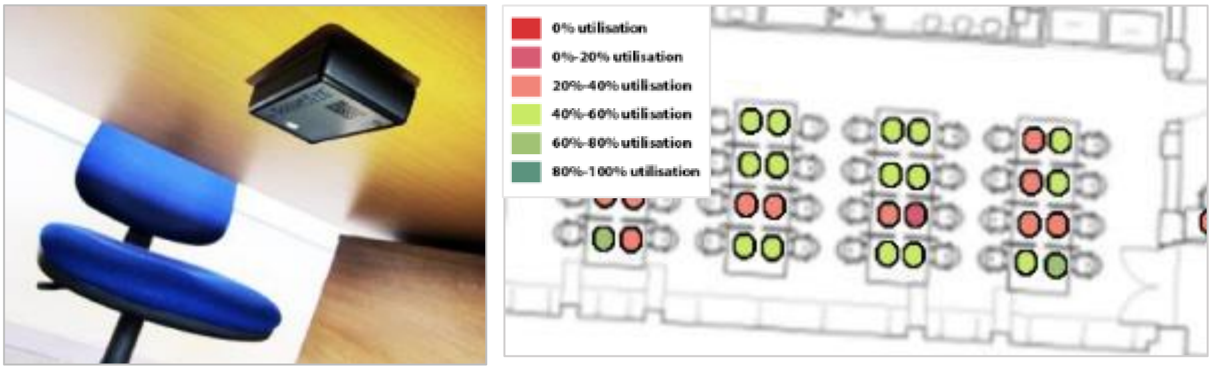


Figure 4. 5 *PIR sensor boxes located underneath desks at UCL libraries (left) Representation of occupancy at each seat in Occupy Cloud (right)*

4.3.4 Quantification of daylight availability

The measurement of horizontal illuminance using spot measurements does not allow for long-term monitoring of desk occupancy based on daylight availability on the desk. Therefore, in this study, parametric modelling and daylight simulations were used to get information about daylight availability, and they were validated against spot measurements with daylight availability on a specific day and time.

In order to analyse the role of daylight availability on seating selection, AutoCAD and Rhino were used to produce 2D and 3D drawings of the library. Then, Grasshopper was used to create lighting performance analysis for the parametric modelling with Ladybug and Honeybee plugins. For the model calibration, spot illuminance measurements were taken using a KONICA MINOLTA illuminance meter and luminance gun meter. The details were described previously in Chapter 3, **section 3.3.4.**

In this study, daylight availability on desks was calculated in two ways using the Daylight Factor (DF). The former method utilizes the daylight factor (DF) obtained from daylight simulations to assess daylight availability annually. The latter method combines the daylight factor (DF) on each desk with the external illuminance data for London provided by Public Health England on a 10-minute basis throughout the year.

In the description of daylight availability on the desks, some terms such as lack of daylight, insufficient daylight and high level of daylight were used in this study. These terms were designed based on the thresholds suggested by EN 12464 Light and Lighting. The recommended lighting level for library reading rooms should be between 300-500 lux to allow for proper reading and writing, with 500 lux being the optimum. Less than 200 lux was not acceptable for reading and writing activities; therefore, this range was described as *'lack of daylight'*. The middle range between 200 and 300 lux was designated as *'insufficient daylight'* because it is considered as acceptable for reading and writing but does not provide the optimum lighting conditions for libraries. On the other hand, more detailed works that require significantly more lighting in places such as laboratory classrooms require lighting between 500 and 750 lux; thus, this range was designated as *'high level of daylight'*.

4.3.5 Methods of analysis

4.3.5.1. The analysis based on average annual occupancy

The data obtained from the UCL library occupancy monitoring system was analysed to understand what type of spaces were most in-demand in the library and the role of daylight on seating selection. A typical day considers all the occupants of a given type for a year of operation and is calculated considering each desk's average occupancy rate in this analysis. The data used in the analysis considered the utilisation of 69 desks in the UCL Bartlett Library between 9:00 and 20:00 on weekdays and between 11:00 and 18:00 on Saturdays (opening hours) between the 1st of January 2018 and the 1st of January 2019. The data were analysed in the following ways:

1. **The desks/ rooms/ zones in most and least demand:** The annual occupancy of each desk was analysed to investigate the desks, rooms and zones with the most and least demand, hence, the popularity of the desk and its relationship with daylight availability.

2. **Order of preference of desks on a typical day:** The degree of freedom of choice could influence the seating decision because individuals can choose only available seats. For instance, they could have more chances to select desks early in the morning than those who arrive in the afternoon. Thus, the selection of desks in the morning hours was analysed. The analysis was conducted on weekdays from 9:00 to 12:00 at 30 min intervals. The 30-minute time interval was defined because a student averagely occupies the seat for at least 31.8 minutes in the morning hours at the Bartlett Library. In order to

investigate which desks were preferred earlier than others on a typical day, the percentage of the time a desk was occupied between 9:00 and 12:00 for an entire year was considered (**Table 4.1**). It was limited to noon because the library reaches the first peak of occupation at midday on a weekday (See more detailed information about the occupancy of the library in **Appendix 3**) The occupancy rate of a desk on a specific date and time is calculated with the ratio of occupied cases to total cases throughout the year. If a desk was occupied at equal to or more than 90% of the year (acceptable confidence interval in studies with small sample sizes), then that desk was regarded as occupied. **Table 4.1** represents the utilization of Desk 1 for a year in the morning hours. For instance, this desk was typically utilised at 13.8% between 9:30 and 10:00 in 2018-2019. Therefore, this information could be used to compare the utilization of this desk with others' utilization within this time frame to understand which desk was preferred earlier than others and the potential reasons.

Table 4. 1 *Method of analysis for the occupancy of each desk at a specific time interval (1: occupied, 0: unoccupied)*

	Time of the day					
Date	**9:00-9:30**	**9:30-10:00**	**10:00-10:30**	**10:30-11:00**	**11:00-11:30**	**11:30-12:00**
01.01.2018	1	1	1	1	0	1
02.01.2018	1	0	1	0	1	0
03.01.2018	0	0	0	1	0	1
04.01.2018	1	1	1	1	0	1
⋮	⋮	⋮	⋮	⋮	⋮	⋮
31.12.2018	1	0	1	1	0	0
Occupancy	10%	13.8%	35%	48%	57%	82%

3. **Length of stay at the same desk:** In addition to the frequency in selecting a desk and its order of preference on a typical day, how long the desk was occupied and free periods, the number of instances where there has been a consecutive period of no usage could also be other critical factors in understanding the students' seating preference behaviour. Therefore, the length of stay at the same desk was analysed to understand how long the desk was utilised without interruption or becoming vacant on a typical day. The analysis was conducted on weekdays from 12:00 to 20:00 with an hour interval. The time period was defined as 12:00 to 20:00 because usually, the seats at the library are very busy during this period, and it allows for an investigation into how long the desks were occupied. An hour interval was defined because a seat was occupied on average for at least 63.5 minutes in the afternoon. If a desk was occupied at equal to or more than 90% of an hour, then that desk was regarded as occupied. Occupancy at equal to or more than 90% of the time was regarded as occupied because a 90% confidence interval is acceptable in social sciences with especially small sample sizes [162].

4.3.5.2. The analysis based on 10-minute based occupancy

Throughout the chapter, the daylight factor was used to predict the internal illuminance on the desks and evaluate the occupancy level of each seat depending on daylight availability. Although DF is one of the good quality metrics to express the quantity of daylight illuminance, it has some restrictions because it only concerns the proportion of internal and external illuminance under overcast sky conditions. The daylight factor is represented in the worst-case sky conditions and gives the minimum values; however, sky conditions are not constant as assumed because of absolute sky luminance. DF gives an insight to daylight availability on desk planes, which can be compared to the overall utilisation of desks in the library, however there is still a lack of information on students' seat preference in relation to instantly changing illuminance levels on desk planes. For this reason, additional research was required to investigate the impact of daylight availability on student seat selection in the UCL Bartlett Library.

Daylight factor (DF) is defined as the ratio of the light level inside a structure to the light level outside the structure (See **Equation 3**). In other words, if the DF on the desks from daylight simulations and the external illuminance in the city at a specific time are known, the internal illuminance on the desk at that time can be accurately estimated and then, assessed based on desk utilisation at that time. From this point of view, instant illuminance on the working plane of the specific desk was obtained from this point using a combination of daylight simulations and external illuminance data at a specific time. External illuminance data for a specific time period on a specific day was obtained from Public Health England under the Open Government Licence.

Equation 3. *Calculation of daylight availability using Daylight factor and External illuminance*

$$DF = 100\,x\ (E_{in}\ /E_{ext})$$

Ein = illuminance due to daylight at a point on the indoor working plane

Eext = simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of the overcast sky.

Within this concept, the below figures (**Figure 4. 6**) show the daylight availability on the desk calculated by **Equation 3** and the occupancy status of Desk 1 from 1 January to 29 January between 9:00 am, and 10:40 am. The daylight availability for each desk was calculated using the previous equation with the combination of DF and external illuminance in London at a specific time and compared to occupancy status obtained from motion sensors at that time interval. For instance, as highlighted in the figure, Desk 1 was unoccupied from 09:00 to 09:10 on 12 January 2018 with 57.94 lux daylight availability, whereas it was occupied between 9:10 and 9:30 on the same day with 69.07 and 77.08 lux daylight availability, respectively. Similarly to this example, a year of utilisation and daylight availability data was assessed for each desk and a logistic regression was performed between desk occupancy and daylight availability to determine whether a high level of daylight encourages a desk to be more occupied.

Case	Desk number	Date	09:00						10:00			
1	1	01/01/2018	41.412	48.546	51.156	55.854	56.55	65.424	62.814	63.336	73.776	84.39
2	1	02/01/2018	13.224	18.444	29.754	30.45	32.364	37.758	61.074	43.5	36.714	32.886
3	1	03/01/2018	33.582	60.726	69.426	63.684	63.51	99.354	123.888	146.682	307.98	258.564
4	1	04/01/2018	12.354	23.664	48.72	64.728	132.24	126.15	155.208	148.944	116.406	146.16
5	1	05/01/2018	22.968	34.452	47.502	99.354	96.57	88.392	111.534	124.758	145.812	247.602
6	1	06/01/2018	48.546	53.592	69.252	110.142	110.49	136.416	148.074	226.374	200.796	222.372
7	1	08/01/2018	13.746	16.878	21.576	23.49	25.752	31.146	30.972	36.714	36.366	41.064
8	1	09/01/2018	11.136	14.094	21.576	22.272	26.622	27.84	27.84	25.578	38.106	30.102
9	1	10/01/2018	64.728	86.652	103.008	139.374	190.53	159.558	158.688	209.496	242.904	191.574
10	1	11/01/2018	32.19	35.844	34.278	37.584	35.67	26.274	28.536	37.062	62.64	61.074
11	1	12/01/2018	57.942	69.078	77.082	89.436	93.264	90.654	97.092	108.402	112.23	107.01
12	1	13/01/2018	54.114	64.38	48.372	65.076	60.03	93.612	107.358	71.166	90.132	110.49
13	1	15/01/2018	23.316	35.148	102.486	68.382	61.596	47.85	41.934	35.148	28.536	37.062
14	1	16/01/2018	96.57	106.14	114.84	125.628	136.764	246.036	338.43	368.358	394.632	424.386
15	1	17/01/2018	96.918	107.706	115.188	124.41	139.026	261.87	332.862	362.094	388.02	411.858
16	1	18/01/2018	103.008	109.272	111.186	116.406	141.636	294.408	368.358	404.376	400.374	453.618
17	1	19/01/2018	109.098	119.886	124.758	130.5	170.346	304.326	355.656	384.888	412.206	436.914
18	1	20/01/2018	30.45	36.888	56.55	61.248	61.422	54.288	60.552	88.218	110.49	148.074
19	1	22/01/2018	91.002	104.922	97.266	169.65	176.958	256.476	172.782	240.642	129.63	376.884
20	1	23/01/2018	12.18	26.796	44.544	43.5	48.894	81.432	76.212	80.388	112.752	137.808
21	1	24/01/2018	18.792	19.662	26.1	90.306	127.194	68.208	48.546	41.934	93.264	85.956
22	1	25/01/2018	154.86	184.44	182.7	233.334	312.852	359.31	395.676	426.648	480.588	500.598
23	1	26/01/2018	37.584	67.338	84.912	135.372	119.364	134.154	166.518	179.046	499.38	212.802
24	1	27/01/2018	136.416	131.718	159.906	178.35	204.624	244.296	281.358	279.096	305.196	327.468
25	1	29/01/2018	77.604	116.058	279.618	346.086	230.028	444.048	214.194	258.738	166.866	143.55

Case	Desk number	Date	09:00						10:00			
1	1	01/01/2018	0	0	0	0	0	0	0	0	0	0
2	1	02/01/2018	0	0	0	1	1	1	1	1	1	1
3	1	03/01/2018	0	0	0	0	0	0	0	0	0	0
4	1	04/01/2018	0	0	0	1	1	1	1	1	1	1
5	1	05/01/2018	0	0	0	0	0	0	0	0	1	0
6	1	06/01/2018	0	0	0	0	0	0	0	0	0	0
7	1	08/01/2018	0	0	0	0	0	0	0	0	0	0
8	1	09/01/2018	0	0	0	0	0	0	0	0	0	0
9	1	10/01/2018	0	0	1	1	0	0	0	0	1	0
10	1	11/01/2018	0	0	0	0	0	0	0	0	0	0
11	1	12/01/2018	0	1	1	0	0	0	0	0	0	0
12	1	13/01/2018	0	0	0	0	0	0	0	0	0	0
13	1	15/01/2018	0	0	0	0	0	0	0	0	0	0
14	1	16/01/2018	0	0	0	0	0	0	0	1	1	1
15	1	17/01/2018	0	0	0	0	0	0	0	0	0	0
16	1	18/01/2018	0	0	0	0	0	0	0	0	0	0
17	1	19/01/2018	0	0	0	0	0	0	0	1	1	1
18	1	20/01/2018	0	0	0	0	0	0	0	0	0	0
19	1	22/01/2018	0	1	0	1	1	1	1	1	1	0
20	1	23/01/2018	0	0	0	1	0	1	1	1	1	0
21	1	24/01/2018	0	1	0	0	0	0	0	0	0	0
22	1	25/01/2018	0	1	1	1	0	1	1	1	1	1
23	1	26/01/2018	0	0	0	1	1	1	0	1	1	1
24	1	27/01/2018	0	0	0	0	0	0	0	0	0	0
25	1	29/01/2018	0	0	0	0	1	0	0	1	1	1

Figure 4. 6 *Daylight availability on the desk (above) and occupancy status of Desk 1 (bottom), from 1 January to 29 January between 9:00 am and 10:40 am*

4.4 Results and Discussion

4.4.1. Description of the data

In this chapter, the utilisation data of the desks obtained from the PIR sensors at the Bartlett Library and daylight availability on the horizontal plane of each desk from daylight simulations were compared to investigate if students tend to make the selection of study spaces with a high amount of daylight. **Figure 4. 7** shows that the average desk occupancy in the UCL Bartlett Library is highly dependent on the term dates with various peak and quiet times during the year, and the overall utilisation of the Bartlett Library was 56.8% during the year. The library reaches maximum occupancy in Springtime (March, April, May), whereas there is not much demand in Summer. April and September are the most and least busy times of the library, respectively.

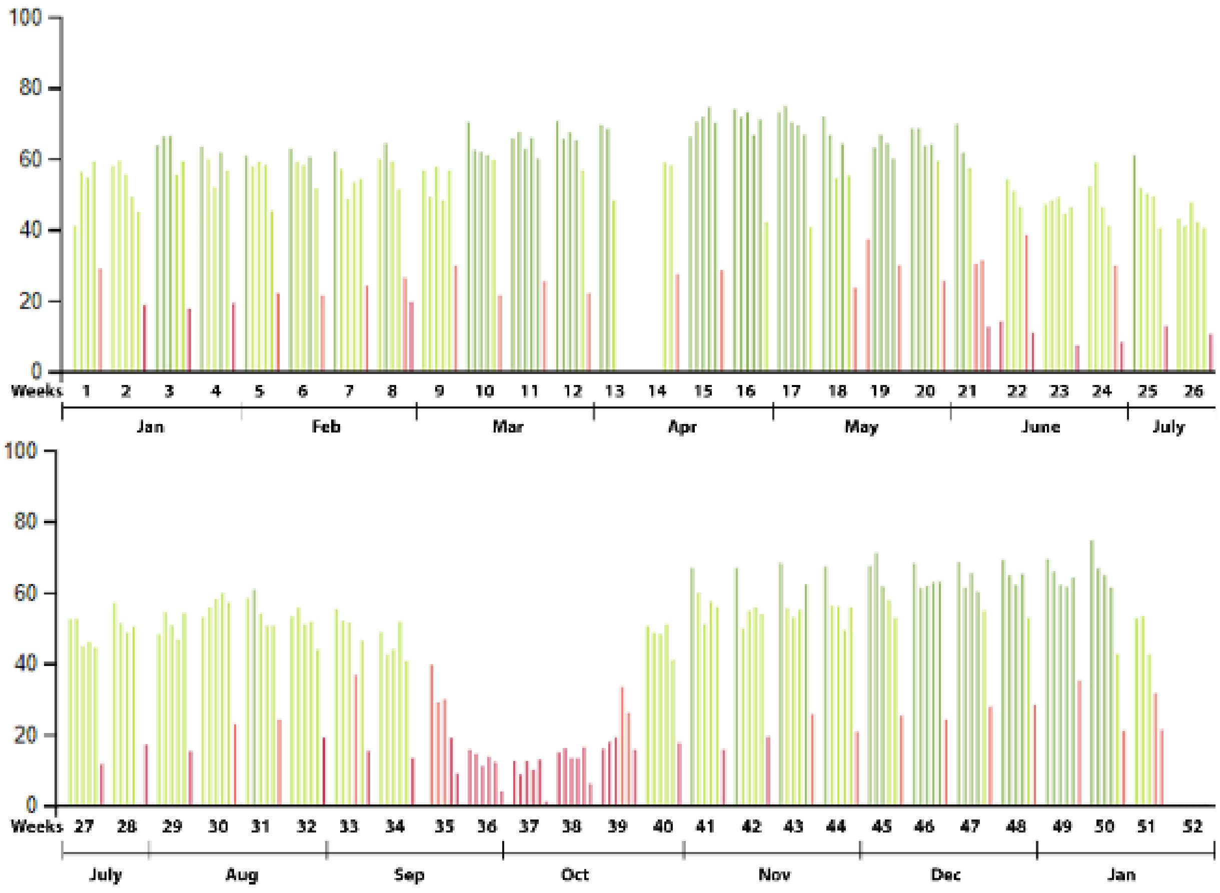
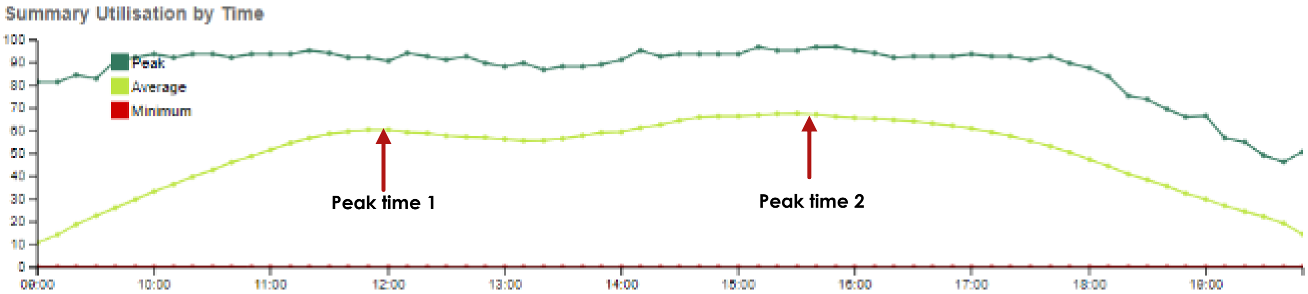


Figure 4. 7 *Average desk occupancy in the UCL Bartlett Library between Jan 2018 and Jan 2019*

As seen in **Figure 4. 8**, on a weekday, the library reaches the first peak occupied time around midday and the second one at around 15:50. In contrast, the busiest time of the day is around 15:30 at the weekend (See more detailed information about the occupancy of the library in **Appendix 3**).



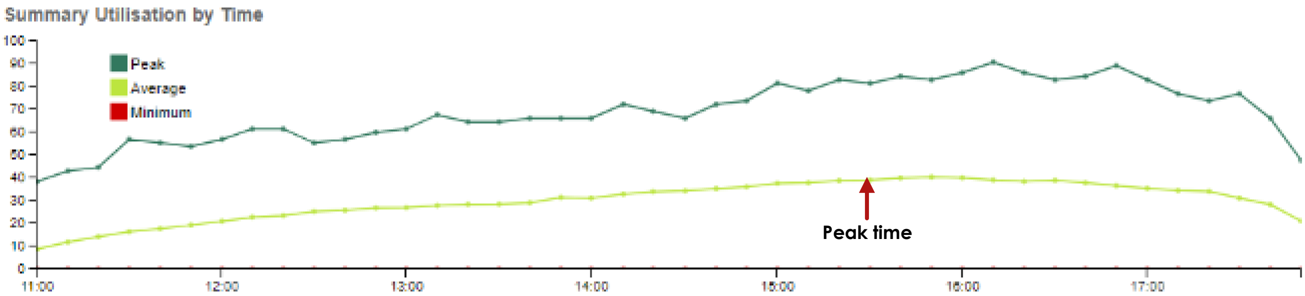


Figure 4. 8 *Daytime occupancy during weekdays (top) and weekends (bottom)*

4.4.2. Desk occupancy rates in the library calculated on an annual basis

In this section, the utilisation of the desks was evaluated specifically using daylight availability to explore the role of daylight on human seating behaviour. This analysis considered the seating preference of the students in terms of the frequency of selecting a specific desk, its order of preference and length of stay at the same desk. In order to investigate the role of daylight in students' seat selection, the annual occupancy rate and order of preference of each desk, as well as the length of stay at the same desk, were overlapped and evaluated with daylight availability obtained from computer simulations.

4.4.2.1. Desks in most and least demand

As presented in **Figure 4. 9**, twelve monitoring sensors showed only 20-40% utilisation on average on the associated desk at the Bartlett Library during the year, whereas forty-five sensors demonstrated 40-60% utilisation. Ten sensors also recorded 60-80% utilisation on the associated desk, all located in Room 2. The average occupancy of twenty-three desks in Room 2 was 64.4%, whereas thirty-two desks in Room 3 were utilised at 53.7% of occupancy hours. Twelve desks in Room 1 were also occupied at 50.5% during the year on average.

Figure 4. 9 indicates that the most preferred desks are located in Room 2, which has access to daylight and an outdoor view. In this room, individual desks were in higher demand than shared desks. Desk 32, an individual desk with both daylight and outdoor views, is the desk with the highest demand. The least utilised desk is Desk 35; it lacks access to daylight, outdoor view, and privacy as it is located close to the circulation between Rooms 2 and 3. The desks in Room 2 were positively appraised by most participants even though they had lower daylight levels than the desks under the skylights in Room 3. This preference could be explained due to the absence of an outdoor view of Room 3 and its open-plan layout, hence the lack of privacy.

Figure 4. 9 *Utilisation level of each desk and daylight availability*

Figure 4. 10 demonstrates the association between the occupancy of the desks annually and the daylight level that the desks received for 90% of the year (the categorisation of lighting levels was done based on the recommended range for library reading rooms). As seen, the increase in the illumination of the desks is generally followed by higher utilisation in the range of 0 to 500 lux. However, the demand for desks with daylight illuminances in the range of 500 lux and above is less than those in the 300 to 500 lux range. The desks above 500 lux are mainly located in Room 3 under the skylight, and they have less demand than desks in Room 2 despite a much higher amount of daylight availability due to a lack of outdoor view and privacy. It can be concluded that the increase in daylight availability of the desks generally leads to an increase in utilization; however, the

layout of the room and other influential factors such as privacy, quietness, outdoor view etc., could make a difference in the role of daylight on seat selection.

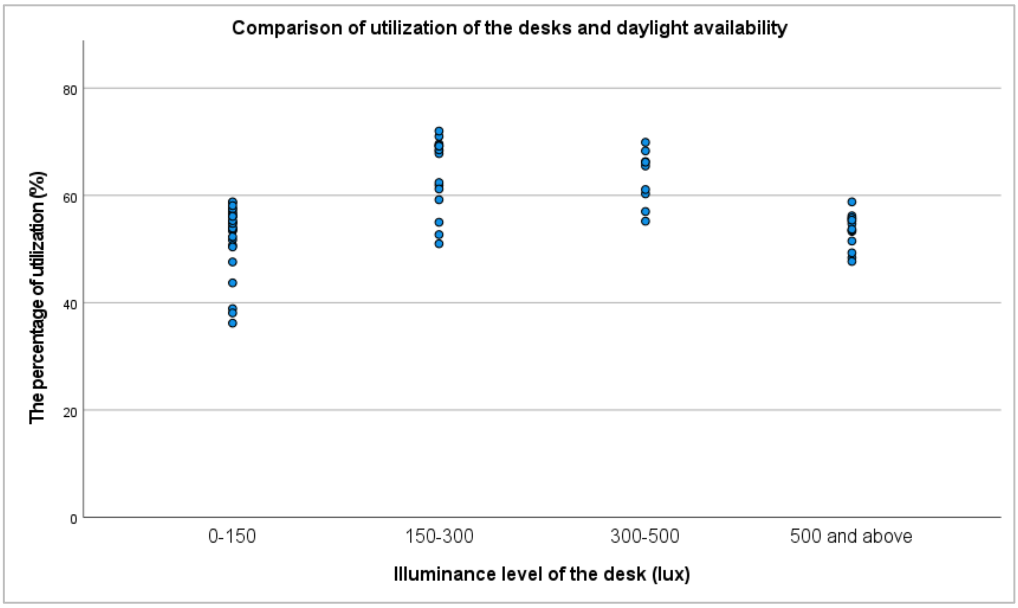


Figure 4. 10 *Comparison of the utilization of the desks and daylight availability*

4.4.2.2. Rooms in most and least demand

As previously stated, Room 1 and Room 2 have several side windows allowing the students to have desks with access to daylight and outdoor views, in contrast to Room 3, illuminated by skylights without access to outdoor views but with high daylight levels, especially at some desks. As seen in **Figure 4. 9**, desks with higher daylight availability on the horizontal plane and illuminated by side windows are those with higher utilisation. The highest utilization belongs to desks near a window, followed by desks with access to outdoor view and less daylight. The desks with no outdoor view and the least daylight are the least utilised. Although daylight does not seem to affect the utilization of desks lit by the skylights in Room 3, desks under the skylight still show the highest utilisation. It can be interpreted that daylight promotes seat selection in places daylit by the side windows; however, the importance of daylight on seat selection under the skylight is relatively less critical than in rooms lit by side windows. Access to outdoor views and acceptable daylight levels make specific seats preferable to seats with only adequate levels of daylight, such as those in Room 3. Privacy could also affect the seat selection in Room 3 (open plan). These findings emphasise that although daylight is one of the essential factors for seat selection, seat preference cannot be explained by daylight alone. It should be investigated together with other components such as privacy, outdoor views, and quietness.

4.4.2.3. Zones in most and least demand

The Bartlett library provides various layouts in the rooms with different kinds of daylighting designs. The library was split into some zones (**Figure 4. 11**) depending on the similarity of layout, privacy, outdoor view and daylight conditions and the features of the zones were explained in Chapter 3, **section 3.3.3.** In this way, it was aimed to analyse the seating preference of the students considering not solely daylight but also its combination with other factors. It is considerable because previous research has shown that the decision of seat selection arises from various factors; such as daylight level [90] [126], ambient temperature, type of furniture, proximity to other occupants [127], quietness, outdoor view, privacy, social interactions such as close to friends, entrance or circulation [105], students' degree of territoriality and seat arrangements [128].

Figure 4. 11 *Zoning of the library depending on the common features*

Figure 4. 12 shows the daily utilization range of each desk in the defined zones. As seen, Zone D has the highest utilization, followed by Zone C, providing individual desks. Surprisingly, the desks in Zone B have utilization between 50% and 60%, although they do not have accessibility to daylight and outdoor view but facing to the wall. Also, some shared desks in Zone A were significantly low utilised despite daylight availability. It could be interpreted that although daylight significantly impacts seat selection, its combination with outdoor view, privacy, quietness and other factors is also vital.

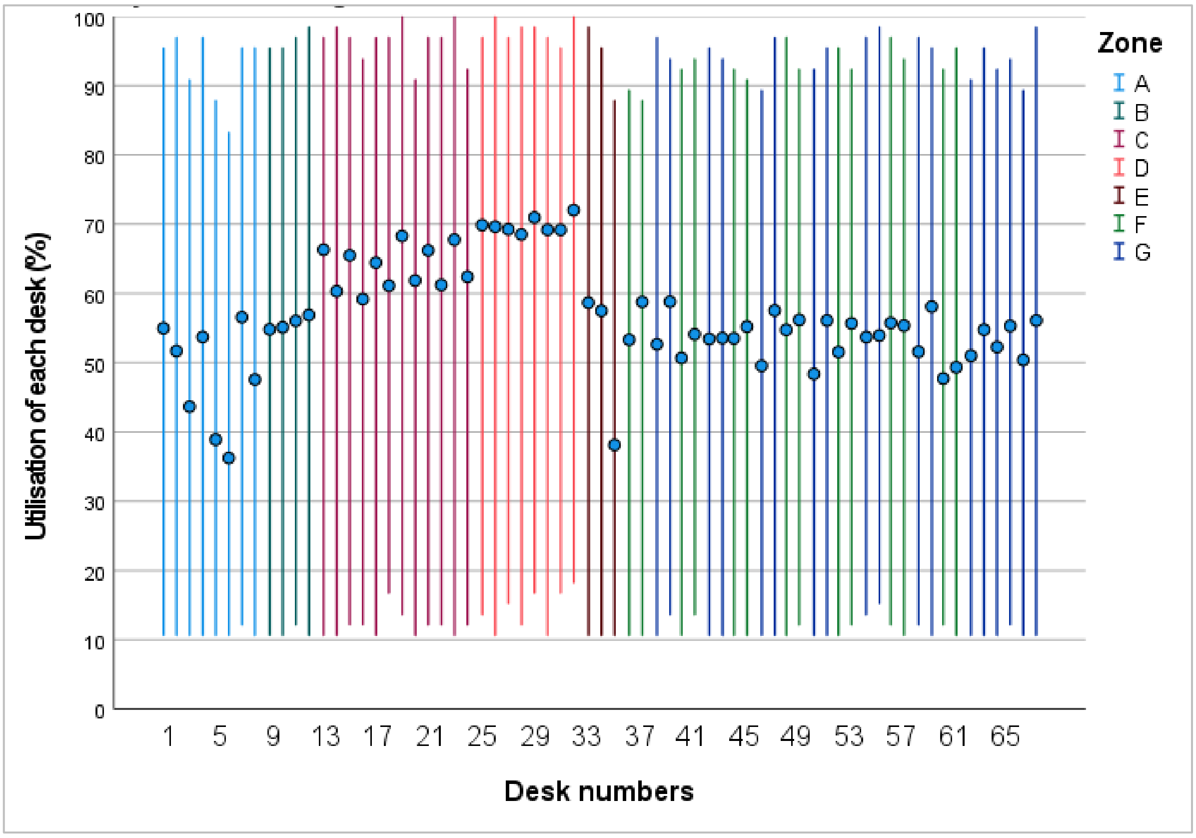


***Figure 4. 12** Daily utilization range of each desk within the zones with different features between 2018 and 2019*

Figure 4. 13 presents the demand for the desks in different zones depending on the overall daylight availability. As supported by previous findings, although the desks in Zone F provided the highest amount of daylight availability, they were not preferred at the most correspondingly. In contrast, the desks with the second and third highest daylight availability, Zone C and D, were positively appraised by most students. Despite the less daylight availability, the desks in Zone D were more selected than those in Zone C, most likely because of privacy. Also, the mean of the utilization of the desks in Zone E was more than 40% in a day, surprisingly, although they do not have access to both daylight and outdoor view. These findings emphasise that although daylight is significant for seat selection, especially in the rooms lit by side windows, other factors also make a difference along with the daylight conditions in the students' seating decisions.

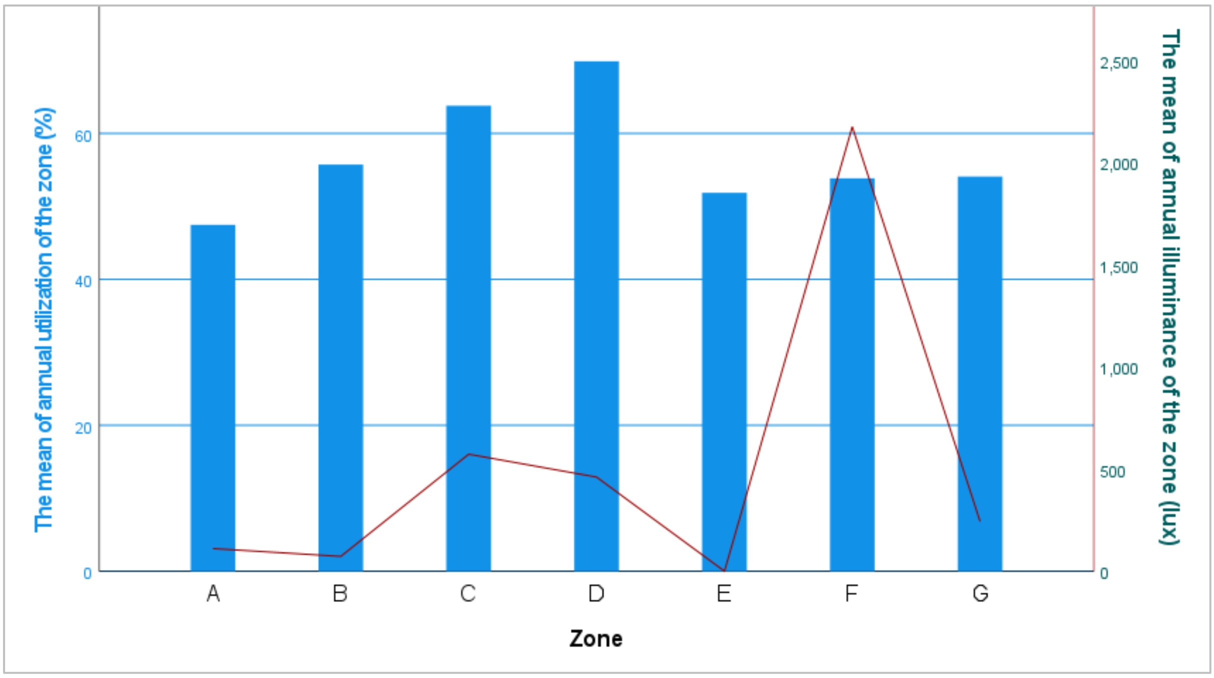


***Figure 4. 13** Comparison of the seat preference in the zones depending on daylight availability*

4.4.2.4. Order of preference for students' seat selection

The previous section has shown that some desks have more demand than others. However, the degree of freedom of choice could also influence the seating decision because individuals can choose only available seats or space. For instance, individuals could have more chances to select a space in the early morning than those arriving in the afternoon. Thus, this section aims to analyse the students' sitting behaviours in the early morning hours. This analysis has been conducted considering weekdays from 9:00 to 12:00 because the library reaches the first peak of occupation time at around midday on a weekday. **Figure 4. 14** shows the utilization of the desks in the UCL Bartlett Library in the early morning hours, in other words, the order of students' seat selection when all desks are available for selection. **Figure 4. 15** simplifies the utilization ranges presented in the previous figure as occupied and unoccupied.

As seen, first comers to the library mostly prefer the individual desks in Room 2. These desks mostly have a good combination of daylight, outdoor view and privacy, but they are not necessarily the ones with the highest daylight availability. Following, students seem to prefer the shared desks in Room 2 with an outdoor view and comparatively less daylight availability and less privacy. After the desks in Room 2 are fully occupied (between 10:00-10:30), students initially select desks in other rooms, mostly with the highest daylight levels and far away from other people as much as possible. Then, desks getting a high amount of daylight in Room 3 are fully occupied, and students begin to select the other desks in the same room with the lack or insufficient daylight levels. These desks mostly have the least daylight availability with no privacy and outdoor view. Corner desks were preferable in this period because they are comparatively more private than others. Although the desks near the window in Room 1 have access to daylight as much as some desks in Room 2 and have a similar outdoor view, these are not preferred by students firstly. It could be explained that Room 1 has a North orientation and is comparatively darker than Room 2, especially in the early morning hours. Another reason that could explain this situation might be the size of the room. Also, the individual cubicles facing the wall in Room 1 are selected earlier than shared desks by the window, probably due to privacy reasons.

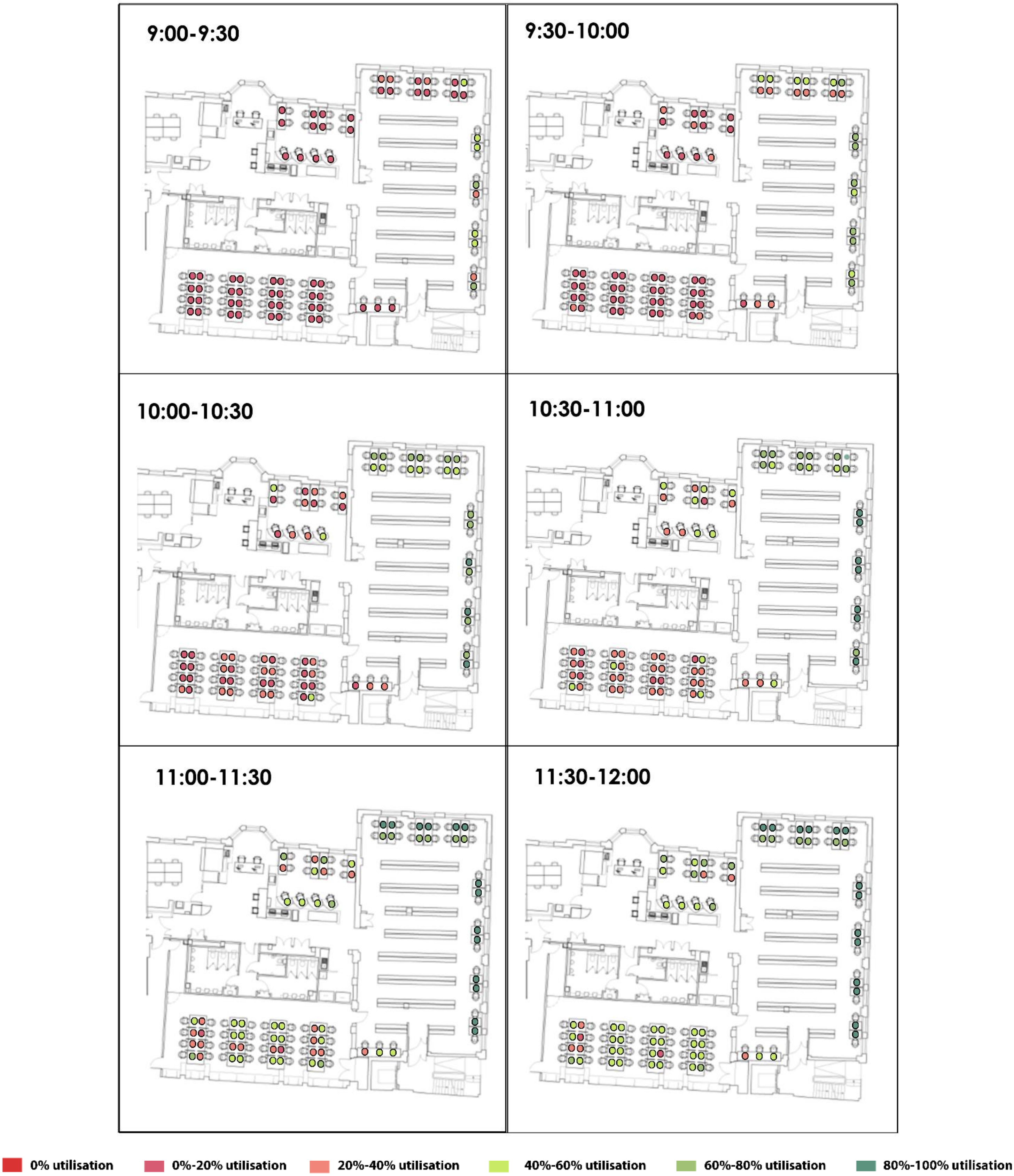


Figure 4. 14 *Seating preference of the students in the early hours on a typical day (%)*

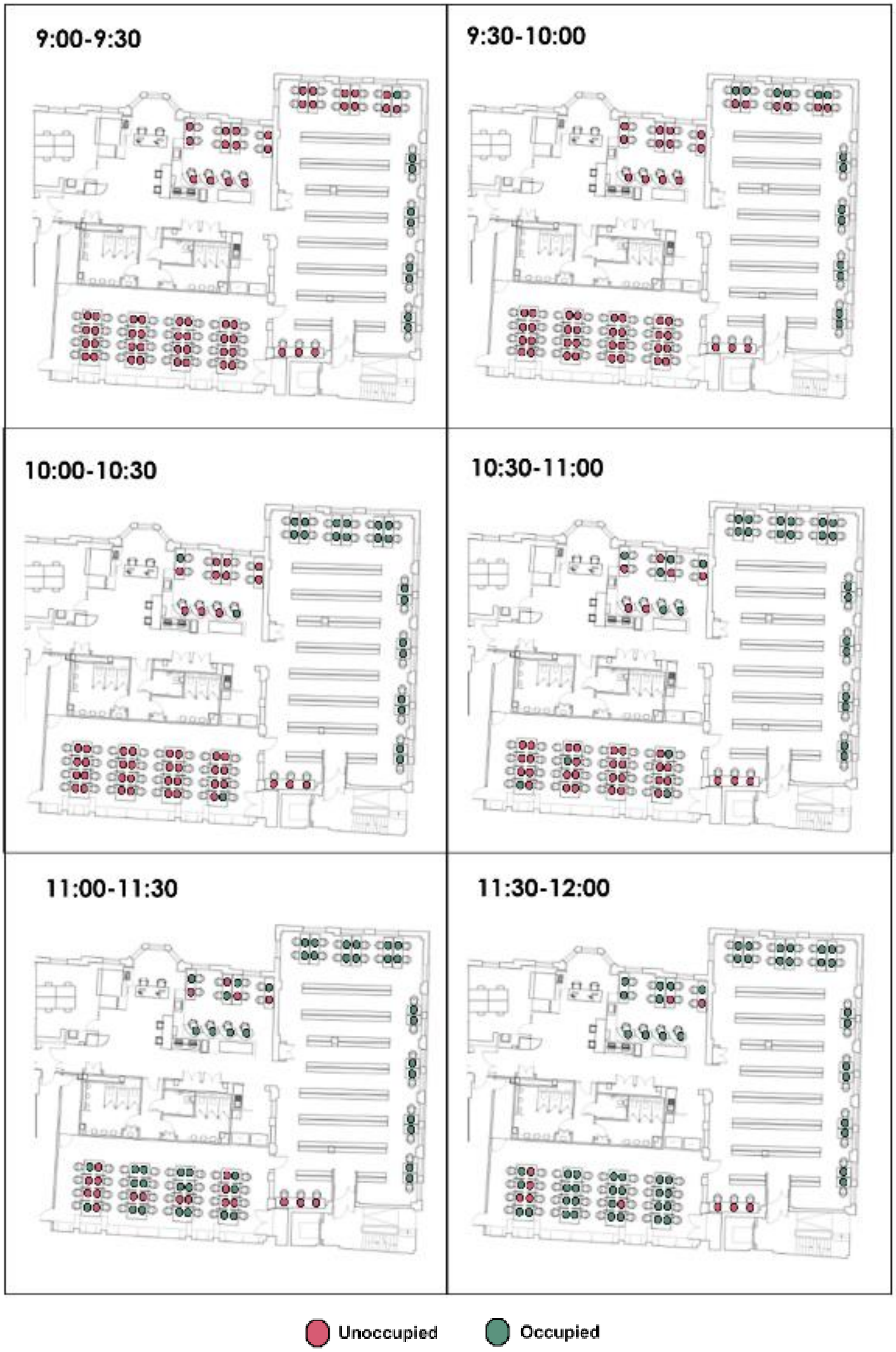


Figure 4. 15 *Seating preference of the students in the early hours on a typical day*

Figure 4. 16 shows the range of daylight availability at the selected desks in the early hours at the Bartlett Library. As supported by previous findings, students do not initially prefer the desks with the highest daylight availability at the library. However, they are likely to prefer the desks with the highest daylight availability in the most preferred space, providing not only daylight but also outdoor view, privacy etc., such as in Room 2 in this study. When that space is fully occupied, they prefer the desks with the highest daylight availability in the less demanded space, such as in Room 3. These findings show that a high amount of daylight promotes people to select particular places; however, the role of daylight should be considered with the combination of other factors.

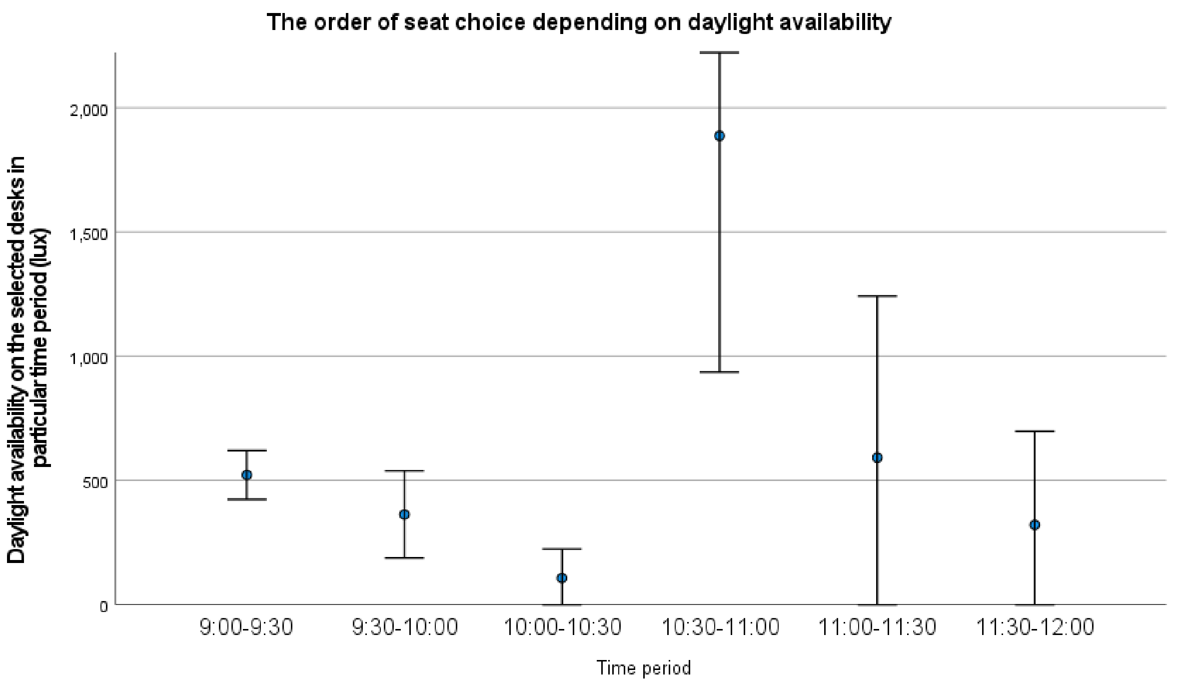


Figure 4. 16 *Daylight availability of the seating preference of the students in the early hours on a typical day*

4.4.2.5. Length of stay at the same desk

The length of stay at the same seat could also matter to investigate the importance of daylight on students' seat preference as in the frequency in selecting a desk and its order of preference on a typical day. The analysis was conducted on weekdays from 12:00 to 20:00 with an hour interval. An hour time interval was defined because a seat was occupied on average for at least 60 minutes in the afternoon. The time period was defined as 12:00 to 20:00 because usually, the seats at the library are very busy during this period.

As seen in **Figure 4. 17**, the desks in Room 2 were utilised most of the day without interruption or becoming vacant. However, desks in Rooms 1 and 3 seemed to be used for shorter periods, especially after 17:00. As supported by previous findings, individual desks in Room 2 were continuously used, followed by shared desks in the same room. The desks in Room 3 used for extended periods were mainly those located under the skylights and those located in the corners despite the lack of or insufficient daylight levels. Interestingly, individual cubicles in Room 1 showed a continuous utilization against shared desks in the same room despite the access to outdoor view and daylight availability.

In order to assess the impact of daylight availability on seat selection, the difference in seating selection before and after sunset was also analysed. At this stage, it was expected to see a noticeable decrease in seating selection after sunset at the places with a good level of daylight, considering that daylight is the reason for their selection. The findings showed that the occupancy of the desks with higher daylight during the period after sunset was not changed as expected, probably due to access to outdoor view and privacy reasons. Some studies also showed that people tend to select the places with access to outdoor views enabling the sky view at night even if there is no daylight.

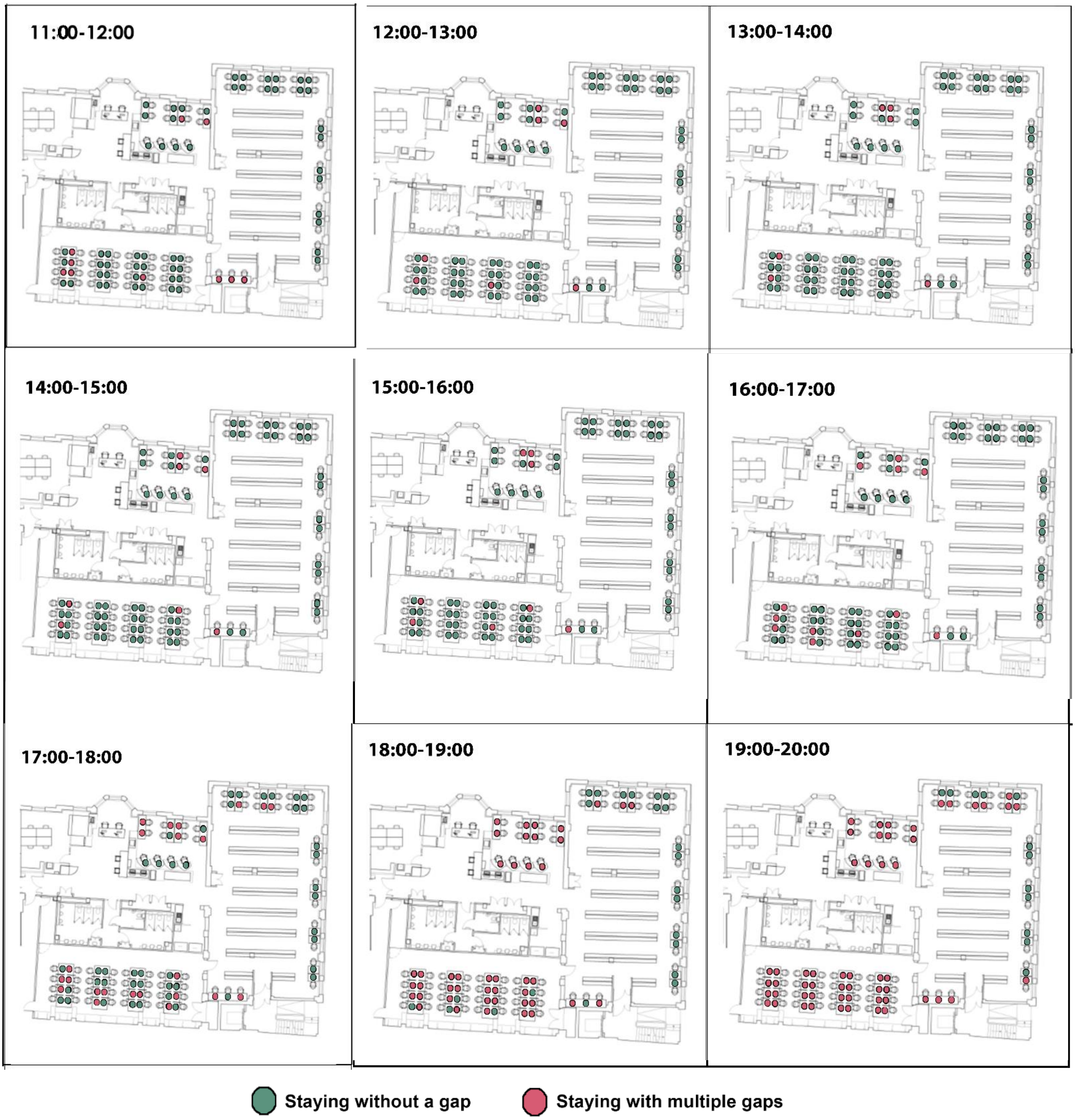


Figure 4. 17 *Length of stay at a same desk on a typical day*

As supported by previous findings, the desks in Room 2 are usually more occupied than desks in other rooms during the day. The desks with 80-100% utilization in a particular part of the day consist mostly of the individual seats in Room 2 that have access to both daylight and outdoor view. Similarly, earlier selected and more consistently occupied desks in Room 3 are mostly the seats under the skylight with a high amount of daylight.

From the point of the length of stay at the same desk, the desks in Room 2 have a high range of utilization, and they are usually utilised during a big part of the day without a gap. However, utilization of a desk in Rooms 1 and 3 usually is not consistent as in Room 2; therefore, the length of stay at a desk seems much shorter. The desks in Room 3, particularly desks getting a high amount of daylight, are highly utilised without a gap at only a part of afternoon hours. Although these findings demonstrate the importance of daylight conditions in seat selection, the characteristics of the space should be considered carefully, including daylight conditions, privacy, outdoor view, layout, etc., while considering the reasons for seat selection [162].

4.4.3. Desk occupancy rates in the library calculated on a 10-minute basis

This analysis was conducted each day from 1 January 2018 to 1 January 2019 between 9:00 am and 8:00 pm every 10 minutes to investigate if a high level of daylight encourages students to select specific desks. For this aim, logistic regression with 1.380.000 cases was conducted. The findings revealed a significant relationship between daylight availability on the desk and occupancy status. In other words, regardless of the other seating features, such as allowing a good outdoor view, quiet space or privacy, daylight conditions on their own have a significant role in the students' seat selection ($p<0.01$, Exp(B)=0.87). For this reason, seat selection could be taken into account as an indicator of daylight perception of the students in further studies to identify inter-individual differences in students' daylight perception due to cultural background.

4.4.4. Limitations

Although the data collected through the sensors indicate whether the space is in use or available, demonstrating which desks are most preferred, each sensor can only report on the state of the desk it is assigned to, and these devices do not collect any personal data and cannot identify an individual. The collected information is binary: either somebody chose that seat at a specific time or has not. Therefore, study results do not represent students' personalities, individual perceptions and expectations. We do not know who that somebody is, nor can we identify if the person sitting there now is different from the last time we checked the sensor's status.

Another limitation is that occupancy does not entirely always based on human existence. Students occasionally leave their laptops, water bottles, and backpacks to claim a seat while they go outside. PIR sensors can not detect a claimed seat due to no large heat signatures or movement. This situation could affect the students' freedom of choice and ultimately study findings because it assumes that it is available for selection if a desk seems unoccupied. Also another limitation could result from the assumption that all sensors had been working properly during the year. Therefore, the time period when the sensor was out of order is regarded as non-occupied, and this situation could significantly change the analysis.

4.5 Summary

In this chapter, data obtained from the UCL library occupancy monitoring system was analysed to understand what type of desks were more in demand during 2018 and 2019. Then, the utilisation of the desks was evaluated using daylight availability to explore the role of daylight on human seating selection. This study considered the seating preference of the students in terms of the frequency of selecting desks, the order of preference and the length of stay at the same desks.

The study findings showed that most of the seats selected as the best were located in areas with high illumination. However, the seats with a good combination of daylight, outdoor view, and privacy were in more demand than those with only a high daylight level. It was also demonstrated that the increase in the illumination of the desks is generally followed by higher utilisation in places daylit by the side windows rather than skylights. It could be argued that access to outdoor views and favourable daylight levels makes the seating places preferable than only daylight. Privacy seems to be another critical component because the area lit by the skylight is an open-plan space that is less private than other rooms. However, although some desks in Room 3 provide a high level of daylight, they were not chosen as expected, most likely due to public feeling and the lack of an outdoor view in this room.

The large-scale database analysis was conducted with more than a million cases assessing the daylight availability of the desks and occupancy status showed that regardless of the other seating features, daylight conditions have a significant role in the students' seat selection, and a high level of daylight promotes students for seat selection. From this point, it can be assumed that the daylight level at the selected desk could represent how much daylight level the student expects from the space. Therefore, seat selection, as a method, will be considered an indicator of the students' daylight perception in the following phase of this study to understand if their cultural background influences the daylight perception of the students.

CHAPTER 5: Cultural Background In The Lit Environment

5.1 Introduction

The previous chapters in the thesis purposed to provide an overview of daylight perception to establish the extent to which assessment methods of daylight perception have already been used commonly and to develop a methodology to investigate the individual differences in the perception of daylight conditions. Following that, it was necessary to define a conceptual framework of cultural background in the lit environment to evaluate the inter-individual differences in daylight perception due to variations in cultural background.

In environmental terms, culture represents the climatic and indoor conditions people have experienced during a significant part of their life. Consequently, people exposed to different cultures might have different expectations of the lighting environment. Knowing the lighting expectations due to cultural experiences has numerous advantages; it could help meet the occupants’ needs and preferences and provide occupant satisfaction, reducing unnecessary energy consumption in the built environment. This chapter aims to identify, evaluate, and summarize the findings of all relevant individual studies using a systematic review to create a conceptual framework of cultural background in the lit environment, which could help understand the impact of cultural background on daylight perception.

5.2 Methodological approach

A systematic review was conducted to define the conceptual framework of cultural background in the lit environment in order to investigate whether individuals' daylight perceptions vary depending on their cultural backgrounds.

5.2.1. Framing questions for a review

The systematic review is reported following the PRISMA Checklist (Preferred Reporting Items for Systematic Review and Meta-Analysis) [163]. Published studies in this field consist of various quantitative and qualitative studies, designed as correlational, cross-sectional, longitudinal, or retrospective, often with specific contexts and small sample sizes. Thus, the range of the reviewed study methodologies includes environments that are analogous in some ways to the situations that people will encounter.

Inclusion and exclusion criteria

The inclusion criteria applied in the systematic review were: **(a)** including at least one aspect of (day)lighting perception, **(b)** published in English, peer-reviewed journals excluding conference proceedings and books, and **(c)** published during any year from 1990 to November 2022. The systematic review was restricted to the timeframe from the date when the acceleration of research in the lighting field started up to now. Scopus, Web of Science, and LEUKOS were searched for electronic records using the keywords detailed in **Table 5. 1** and Boolean search terms.

Boolean operators are utilised by defining the main research question's keywords and their synonyms. They make the search easier by using 'AND' to combine the keywords, 'OR' to broaden and 'NOT' to eliminate. This is how the Boolean search was carried out: For the Boolean search, the keywords from Group 1 (intervention) and Group 2 (outcome) in **Table 5. 1** were combined. As an example, the keywords were combined like this; keywords in Group 1 **(***Culture** **OR** *"Prior light* *history”* **OR** *“Previous light history*" ..**) AND** the keywords in Group 2 **(***“Daylight perception”* **OR** *“Light perception”* **OR** *“Daylight expectation”*…**).** These keywords were identified to find all the relevant keywords for the topic to ensure the search is comprehensive with different spellings, tenses and word variants of keywords, synonyms and related concepts.

The potentially relevant research articles were identified by defining keywords which were searched within each database using the combination of the keywords from Group 1 and Group 2 (Boolean search terms). The search was done in either title, abstract, or keywords of the papers in the Scopus and Web of Science databases. Keywords were searched anywhere in the high-quality Light and Lighting database (LEUKOS) because the database did not allow search in abstracts or titles. After downloading the papers from LEUKOS, they were eliminated manually to meet the identified criteria.

Table 5. 1 *Used keywords in the systematic review*

Databases	Group 1: Intervention	Group 2: Outcome
Scopus In Article title, Abstract or Keyword **Web of Science** In Article title, Abstract or Keyword **LEUKOS** In anywhere, then manually checked if it applies to criteria	**Culture** Prior/Previous light history **Prior/ Previous luminous environment** Previous climatic conditions **Daylight experience** Luminance history **Long-term light experience** Past daylight experience **Local illuminance** Country of origin **Latitude** Immigrant **Sociocultural** Vitamin D	**(Day)light perception** (Day)light expectation **(Day)light satisfaction** User expectations **(Day)lighting sensitivity** (Day)lighting tolerance **(Day)light adaptation** Visual comfort **Discomfort glare**

5.2.2. Identifying relevant work

Identification

In the first stage of systematic review, the titles and abstracts of the journal articles were reviewed and manually excluded if they did not meet the criteria mentioned above. The second stage was the assessment of the full-text articles for eligibility based on the method outlined in PRISMA. The results of the eligible studies were exported to Mendeley, which identified 1189 published research articles.

Screening

Then the duplicates were removed (n=28). Next, they were removed if the title or abstract did not provide relevant information or meet the selection criteria (n=1126). The eliminated papers mostly involved Biology and Photobiology studies on animals, especially rats and some phytoplankton cells. The considered only included those where the association between cultural background and daylight perception (insufficiency (quantity) and inefficiency (quality)), including daylight adequacy and discomfort glare, were assessed.

Eligibility

Then the remaining full-text articles (n=35) were assessed for eligibility with the previously explained procedure, of which 27 papers were excluded from further inclusion as they were deemed irrelevant (e.g., circadian rhythm studies). Those articles were partially related to the research topic but did not answer the research question straight away.

Included articles

Figure 5. 1 presents the process of inclusion of reviewed papers. In addition to the database search, a manual search of all references cited was conducted in relevant articles. This process led to the identification of 39 published articles of potential relevance. These articles were then considered for inclusion in the systematic review according to the inclusion and exclusion criteria described above. Finally, the exclusion resulted in eight relevant research articles that were analysed further for method and content and those articles were presented in **Table 5. 2**.

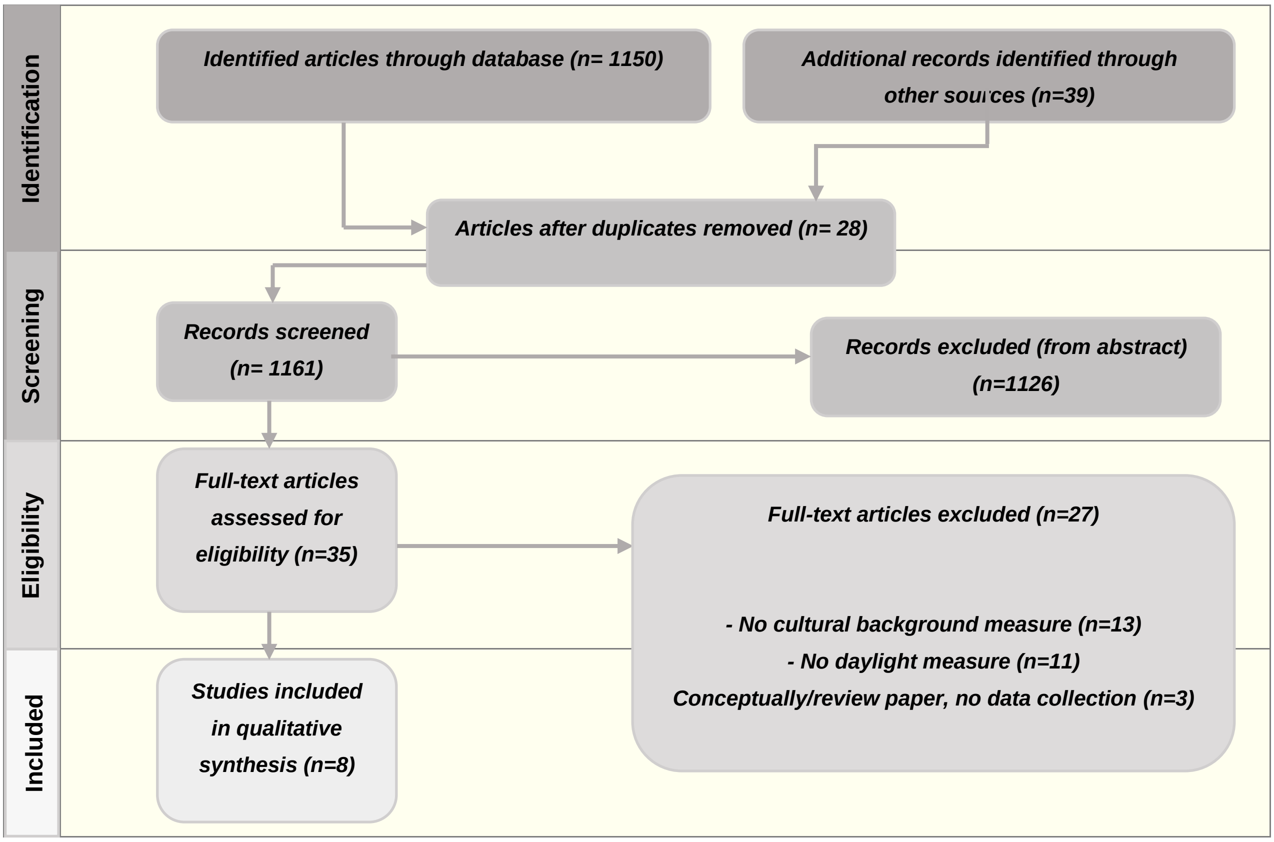


Figure 5. 1 *Flow of information through the different phases of the systematic review The number of studies included in the qualitative synthesis (N=8)*

5.3 Results and Discussion

This chapter aimed to identify, evaluate, and summarise the findings of all relevant individual studies using a systematic review to create a conceptual framework of cultural background in the lit environment, which could help understand the impact of cultural background on individuals' daylight perception. The systematic review identified eight research articles that somehow answered the research question, "What is the cultural background in the lit environment?". After identifying the articles, they were examined, and the similarity in their way of defining culture was noticed. It was found that even though all articles focused on the association between cultural background and daylight perception, they all understood and defined the term of "culture" in the lighting environment differently. For instance, a researcher that assumed culture as the ethnic background ignored where the participants came from, how long and which daylight level they were exposed to, and their habits and beliefs. There is no comprehensive study considering all aspects of "culture" in the lighting field, and this situation makes interpreting the findings challenging. Therefore, they were categorized depending on the approach to the cultural background, and the approaches of eight research articles to culture in the lit environment were presented in **Table 5. 2**. This review highlighted that cultural background in the lighting environment should be evaluated considering **(1)** the ethnicity and/or physiological characteristics of the individual eyes, **(2)** the area (luminance environment) where people used to live, **(3)** the luminance environment they were recently exposed to and **(4)** the sociocultural background of individuals [164]. Identifying the approaches that define the meaning of culture in the lighting environment is key in developing a methodology for assessing the impact of cultural background on daylight perception applied in **CHAPTER 6**.

Table 5. 2 *The studies included in the qualitative synthesis (N=8)*

Reviewed articles	Information about the articles	
Lee and Kim, 2007 [137]	**Approach**	**Ethnicity and genetic origin (physiological characteristics of eyes)**
	Participant interventions	a) Distance (R) between the window and subject b) Horizontal distance between the centre of a window and the subject's eyes (T) c) Vertical distance between the centre of a window and a subject's eyes (H) d) Angle of the window and a subject's direction of vision (Q) e) Position index (P)
	Experiment parameters	a) Window luminance (Ls) (cd/m2): 23000,15000, 8000,5000,3000 b) Background luminance (Lb) (cd/m2): 318,159,63 c) Work place illuminance (lx): 1000,500,200
	Physiological Metrics	a) Visual ability tests to select participants with corrected vision above 1.0)
	Evaluation of vocabulary	a) Glare sensation vote (GSV) (Intolerable - perceptible) b) Discomfort sensation vote (DSV) (very uncomfortable – not uncomfortable) c) Satisfied vote (SV) (very unsatisfied – satisfied) d) Brightness (Intolerably glaring – not glaring) e) Workability (extremely difficult – no change)
	Objective(s)	a) Evaluation of the visual difference between Caucasians and Asians because of the physiological properties of eyes
	Methodology	a) Mock-up b) Analysis of the difference between the previous and present studies' equations c) Establishment of a nomograph
	Number of Participants	42 Caucasians and Asians aged between 20 and 50 (27 female and 15 male with corrected vision above 1.0)
	Key Findings	a) Caucasians felt more discomfort glare at high luminance of 15,000 b) The recovery time for a subject's eyes after exposure to a window with high luminance was different depending on the location of the subject's eyes and window
	Key notes	They just focus on ethnicity regardless of their residence area or prior light history They use the word "culture" as the long-term light history because of their residence.
Kim and Mansfield, 2016 [165]	**Approach**	**The geographic location of residence (the luminance environment where people used to live)**
	Evaluation of vocabulary	a) Lighting quality (Reflection, Flicker, Brightness, Colour rendering, Distribution, Shadows, Overall Comfort) b) Mood (Aroused – sleepy, Unpleasant- pleasant from Affect Grid) c) Lighting appearance (Attractiveness) d) Environmental satisfaction (Efficiency, Overall Satisfaction Suitability, Suitability to the tasks, Preference) e) Eye discomfort (Negative sensitivity, Redness, Tiredness, Dryness (1-5 (higher is better))
	Objective(s)	a) Investigation of the appraisal path in the cultural differences between the UK and South Korea with daylit and non-daylit cafes
	Methodology	a) Two field surveys were conducted in London, UK and Seoul, South Korea. One daylit, and non-daylit café were surveyed in each country, with the participants spending at least 30 minutes in the café.
	Number of Participants	66 customers (49 for daylit, 17 for non-daylit) in London and 102 customers (62 for daylit, 40 for non-daylit) in Seoul
	Key Findings	a) There is a cultural difference in the appraisal path between the UK and South Korea, which would be worth exploring further with different cultural cohorts. b) Appraisal path can be a useful model for determining the effect of luminous conditions on occupant appraisal, preference, mood and health and well-being.
	Key notes	They assume that the people living in the same place have a common culture, but maybe different factors are affecting their light judgements

Saraiva et al., 2018 [166]	**Approach**	**The geographic location of residence (the luminance environment where people used to live)**
	Experiment parameters	a) Dimensions of the classes b) Air quality, c) Thermal comfort, d) Visual comfort and e) Acoustic comfort components were described and compared.
	Evaluation of vocabulary	a) Indoor air quality (Fresh-very polluted) b) Thermal comfort (Comfortable – Very uncomfortable with very warm) c) Visual comfort (Comfortable – Very uncomfortable with very insufficient lighting) d) Acoustic comfort (Comfortable- very noisy) e) Ergonomic comfort (comfortable-very uncomfortable)
	Objective(s)	a) This research addresses the importance of using indicators related to environmental comfort in sustainability assessment tools applied to school buildings.
	Methodology	a) conducted in two different cities, Guimarães in Portugal and Juiz de Fora in Brazil with similar climate conditions (temperature and air humidity). b) adapted version of Ricardo Mateus' thesis was used to assess the Indoor Environmental Quality (IEQ) conditions in the school buildings.
	Number of Participants	269 students in Portugal and 269 students in Brazil aged between 15 and 18.
	Key Findings	a) There is no noticeable variation between the countries. Both Brazilian and Portuguese students have very similar parameters in school buildings. b) There is considerable variability in IEQ between the countries. c) Light satisfaction of them are quite similar (78% in Portugal and 80% in Brazil)
	Key notes	Although these students live in different countries, and they have different cultural backgrounds, their light satisfaction is similar, probably due to similar climate conditions they exposed to.
Brandl and Lachenmayr, 1994 [167]	**Approach**	**The geographic location of residence (the luminance environment where people used to live)**
	Experiment parameters	a) Participants were examined in the altitude simulation chamber of the Aviation Medicine Institute of German Air Force at zero altitudes (= 500 m) and 10,000 ft (ca. 3,500 m height).
	Physiological Metrics	Heidelberg anomaloscope
	Evaluation of vocabulary	a) D-15 test b) Humphrey Field Analyzer
	Objective(s)	a) Testing the dependency of changes in the central visual field sensitivity on different degrees of oxygen saturation
	Methodology	a) Determination of abnormal quotient using a Heidelberg anomaloscope b) Determination of changes in colour vision by saturated and desaturated panel D-15 test c) Determination of differences in light sensitivity for the white, red, blue and green light by a threshold test using a Humphrey Field Analyzer (640) as a perimeter.
	Number of Participants	48 probands (48 monocular tests) 20-50 years of age
	Key Findings	a) At zero level (500 m) hemoglobin- oxygen saturation was 97% +/- 1%. b) At 10,000 ft this value decreased to 83% +/- 3%. Hypoxic hypoxia caused neither significant AQ changes nor did it induce reproducible changes in colour vision by the panel D-15 test. c) Anoxia resulted in significant ($P < 0.01$) differences in light sensitivity in the phototopic range.
	Key notes	It shows that altitude change makes some differences in our light sensitivity.
Kent et al., 2016 [168]	**Approach**	**Previous luminous environment (the luminance environment individuals were recently exposed to)**
	Participant interventions	a) During the experiments, participants were asked to focus attention on a visual fixation point positioned in the centre of a screen whose luminance was slowly raised at a steady rate. b) Subjects were required to participate in the experiment on the same day in four test sessions at 3-hour intervals: Morning: 09:00 or 09:30 , Evening: 18:00 or 18:30 , Afternoon B: 15:00 or 15:30 , Afternoon A: 12:00 or 12:30
	Evaluation of vocabulary	a) Photosensitivity Self-assessed exposure to natural and artificial light, their usage of solar protections such as sunglasses, their luminous routines such as working at a bright or dark condition consistently, and their interaction with environment such as blinds. b) Chronotype

		Questions from the Munich Chronotype Questionnaire (MCTQ) (Roenneberg, Wirz-Justice and Merrow, 2003) c) Glare sensation votes (GSV) d) Temporal variables question assessing participants' fatigue level, caffeine and food intake before the experiment, the most exposed sky conditions and natural-artificial light between test sessions.
	Objective(s)	a) Investigation of the impact of various temporal variables, in other words, the variables covarying with the time of the day and commonly associated personal factors with subjective evaluations of glare sensation as the day progresses.
	Methodology	a) Controlled laboratory experiments with the same participants at different times of the day
	Number of Participants	30 participants
	Key Findings	a) Earlier Chronotype test subjects were able to tolerate higher levels of source luminance for the same reported criteria of visual discomfort at all times of the day. b) There is higher tolerance to source luminance across all criteria of glare sensation throughout the day for subjects not having ingested caffeine. c) Age, gender, ethnicity, food ingestion and self-assessed photosensitivity of participants did not show any statistically significant difference between subjective evaluations of glare sensation. d) There is no influence of fatigue, sky conditions, and prior light exposure on individual glare sensations at different levels of visual discomfort and times of the day.
	Key notes	Although they have found no effect of prior history on glare sensation in this study, they found a significant difference in their further studies.
Martin et al., 2002 [138]	**Approach**	**Previous luminous environment (the luminance environment individuals were recently exposed to)**
	Participant interventions	a) limited time spent outside in the dim week
	Physiological Metrics	a) Baseline and test melatonin suppression
	Evaluation of vocabulary	a) Sleep schedule b) Dim- and bright-week conditions (During the dim week, subjects were instructed to minimise their outdoor light exposure and to wear dark welders' goggles)
	Objective(s)	a) Analysing light exposure history impact on subjective light sensitivity, as assessed by the magnitude of the suppression of melatonin secretion by nocturnal light. b) The hypothesis was that following a week of increased daytime bright-light exposure, subjects would become less sensitive to light and that after a week of restriction to the dimmer light, they would become more sensitive.
	Methodology	a) The protocol was a counter-balanced crossover design, composed of a dim week and a bright week, lasting a total of 14 consecutive days. Seven subjects completed the bright week first, and five subjects completed the dim week first.
	Number of Participants	a) A total of 12 healthy subjects, six females and six males (mean age 25.5) b) None of the subjects was taking prescription medications working night shifts or had travelled through more than two time zones one month preceding the experiment.
	Key Findings	a) This study was the first to show that light sensitivity in humans, as assessed by melatonin suppression to nocturnal light, may be changed by manipulating light exposure history in the previous week. b) Significantly more melatonin suppression after a week of exposure to relatively dim light compared with after a week of exposure to long durations (about 4 hr per day) of brighter light, suggesting higher light sensitivity after the dim week when compared with the bright week.
	Key notes	Although they found that prior light history has an impact on melatonin amount and circadian rhythm, the light exposure time is too short, and it was suggested that it should be tested with more extended studies.
Kawasaki et al., 2018 [169]	**Approach**	**Previous luminous environment (the luminance environment individuals were recently exposed to)**
	Physiological Metrics	a) Pupillography b) Circadian rhythm analysis c) Sleep (derived from rest-activity recordings)
	Objective(s)	a) Testing whether retinal sensitivity, sleep, and circadian rest-activity will change during long-term daylight deprivation on two Antarctic bases (Concordia and Halley VI)
	Methodology	a) Evaluation of retinal sensitivity changes analysing the pupil responses towards different light stimuli. b) Sedentary and active periods continuously measured using activity watches
	Number of Participants	25 healthy people (mean age: 34 ± 11y; 7f)
	Key Findings	a) During long-term daylight deprivation, retinal sensitivity to blue light increases, whereas circadian rhythm stability decreases, and sleep-wake timing is delayed. b) The sleep-wake cycle obtained from the information rest-activity recordings was significantly delayed after the first-month daylight deprivation ($p < 0.05$).
	Key notes	It shows that daylight deprivation for seven months make some changes in our retinal sensitivity and sleep-wake pattern.

Siu-Yu Lau, Gou and Li, 2010 [170]	**Approach**	**Sociocultural background of individuals**
	Evaluation of vocabulary	(a) Background information, (b) Lifestyle and living habits, (c) Design of windows (d) Window evaluation
	Objective(s)	a) Investigation of Human – window interaction in the residential buildings in Hong Kong b) Increase of the satisfaction of the building users in daylight
	Methodology	A questionnaire was conducted between December 2007 and June 2008 to investigate window and human interactions in high-rise residential buildings in Hong Kong.
	Number of Participants	300 questionnaires were circulated in both private and public housings in Hong Kong but only 200 ones were filled out which only 173 were valid for further analysis.
	Key Findings	a) The study results showed that daylighting is not the dominant factor for domestic window design because of Hong Kong' s sociocultural context. However, other factors such as dining habits, views from the living room, and privacy for the bedroom proved to be more important in the users ' perception.
	Key notes	In some cultures, daylight may not be a dominant factor because of the sociocultural context, so their expectation and satisfaction will vary from others

5.3.1. Ethnicity and genetic origin (physiological characteristics of eyes)

Ethnicity approach

Up to now, various criteria have been used to assess ethnicity, including country of birth, nationality, skin colour, national/geographical origin, and religion and language spoken at home [171]. However, it has not been described using only one criterion but a combination of them.

In the existing lighting research, the ethnic background has been considered influential on lighting perception, more specifically, discomfort glare perception (the sensation of annoyance or even pain induced by overly bright sources) assessed through discomfort glare indices. Although the mechanisms governing discomfort glare are still unknown, current indices somehow predict the degree of perceived discomfort glare by approximating a value, but certainly not by defining a precise threshold. Approximating the degree of perceived discomfort glare has been considered a way to assess occupants' satisfaction and well-being [18]. The discomfort glare indices used for assessing glare perception were developed to compare subjects from different kinds of studies and to account for differences in the visual properties of particular groups. These indices were explicitly designed for particular groups, such as the DGI for British subjects, PGSV for Japanese subjects, and DGP for German and Danish subjects [18].

Also, several researchers have assessed discomfort glare perception of subjects from different locations using the DGI, PGSV and DGP indices, despite the indices' thresholds and the interpretation of findings differ from each other. For instance, Subova highlighted the difference in the subjective responses to discomfort glare between subjects in Slovakia and subjects from a similar study conducted in the USA by MacGowan et al. [172]. Furthermore, IWATA et al. noticed a remarkable difference in the discomfort glare sensitivity between Japanese and British subjects [173]. They found that Japanese subjects were less sensitive to higher levels of discomfort glare than British subjects; however, the compared research procedures were not completely the same. Similarly, Lee and Kim found that Caucasians perceived more discomfort with glare at high luminance (15,000 lux) than Asians [137]. However, the researchers ignored participants' area of residence and prior light history and assumed that participants living in the same locations have the same ethnic background.

In contrast, Pulpitlova and Detkova assessed the discomfort glare perception of Slovakian and American subjects using the Hopkinson's discomfort glare scale and pointed out the similarity of their discomfort glare perception even if they have different ethnic backgrounds [174]. Another study conducted by Kent et al. could not find any correlation between ethnicity and participants' glare assessments [168]. However, their further studies found a significant difference in discomfort glare perception of people from different ethnicities. In brief, some researchers found either similarities or differences between the discomfort glare perception of people from different ethnicities. It could be the result of the application of different indices and study procedures, and it requires further attention.

These studies show that ethnicity may be a critical factor leading to how lighting conditions are perceived. Nevertheless, subjects with different ethnic backgrounds may have similar discomfort glare perceptions as long as they lived in the same province and got used to living under those conditions. Therefore, the location from which participants were selected, in other words, study design, could be critical in interpreting the findings.

Genetic origin approach

Several properties and visual characteristics of subjects' eyes have been shown to vary in prevalence by ethnic group. Van den Berg et al. investigated the differences in the optical characteristics and iris colour of Caucasians and Asians. Their research showed a variation in light acceptance between Caucasian and Asian participants, resulting in different pigmentation densities between subjects' eyes [175]. Lee and Kim also researched the discomfort glare perception of Caucasians and Asians [137]. Their study also showed that Caucasians have less tolerance to high glare levels than Asians due to the physiological properties of the eyes.

Similarly, a remarkable difference in light perception was found between light-eyed Caucasians and dark-eyed Asians when the production of the hormone melatonin was suppressed [176]. This research demonstrated that the difference in light-based melatonin suppression is associated with eye pigmentation and/or ethnicity. Therefore, the cultural background in the lighting field should be considered not only ethnic background but also the physical properties of participants.

Up to now, various studies have demonstrated the differences in daylight perception and preferences resulting from ethnicity and/or individual eyes' physiological properties. However, most cross-cultural lighting studies examined discomfort glare perception and colour temperature preference, but they did not focus on the adequacy of illuminance levels. Nonetheless, Belcher argued that understanding cross-cultural illumination preferences are critical since they can affect feelings of well-being and worker productivity [177].

5.3.2. The geographic location of residence (the luminance environment where people used to live)

Many researchers have shown that subjective lighting assessments of the same environment are not often consistent. It could result from the acclimatisation (natural adaptation to specific conditions) of individuals to specific outdoor daylight conditions. For instance, residents in Tel Aviv, where illuminance levels are above 75,000-lux for around 66% of the time, may not have the same daylight expectation as people living in Berlin, where similar illuminance levels barely occur. Hence, external illuminance conditions might significantly affect daylight perception, preference, and expectation. However, the amount of exposed daylight also matters in addition to outdoor illuminance levels.

Pierson, Wienold and Bodart [18] have put forward a new definition of culture as "the climatic and indoor conditions which people experienced during their major part of life." As a result of cultural experiences, human behaviours toward the environment and its expectations are shaped. Consequently, people exposed to different cultures might have different expectations of the lighting environment. In other words, these researchers asserted that even if the subjects are from several ethnical backgrounds, their lighting perception could be similar because of the acclimatisation to the same climatic and environmental conditions resulting from living in the same place [18]. Similarly, Kim and Mansfield showed a noticeable difference in the lighting perception of people living in the UK and South Korea. They also found a remarkable difference in the appraisal path that could be used to determine the effect of luminous conditions on occupant appraisal, preference, mood and health and well-being between people from two locations [165]. A similar study conducted in countries with similar climate conditions showed that 80% and 78% of Brazil and Portugal students were satisfied with the indoor lighting environment in their classrooms against very similar lighting conditions [166]. This situation could be explained that the students' lighting comfort levels seemed comparable due to the similar climate conditions they were accustomed to, regardless of the cultural diversity in these two communities.

Another comparative study between Korean and American subjects indicated that Korean immigrants to the US expressed their discomfort with the new lighting conditions and how challenging it was to accustom them to such different outdoor lighting conditions [137]. Likewise, some researchers found a noticeable difference in the lighting perception of people living at different latitudes or altitudes. A comprehensive study by Subova et al. showed that subjects in Middle Europe living around 30 degrees latitude have a higher sensitivity to lower luminance conditions than people living at higher latitudes because of their adaptability [172]. On the other hand, Brandl and Lachenmayr noticed that the change in altitude causes some physiological alteration in the human body, and therefore people living at different altitudes have different sensitivity to lighting conditions [167].

Acclimatisation to outdoor daylight conditions might affect subjective evaluations of artificial light as well as daylight. A cross-cultural study was conducted by Bodrogi et al. about the preference for perceived illumination chromaticity among Chinese and European observers [178]. In this study, Chinese and European participants were divided into Chinese and European origin, living in Germany and China. Surprisingly, this study pointed out a remarkable difference in the lighting preference of participants residing in Germany and China, regardless of their ethnic backgrounds. Another comprehensive field study was conducted to better understand the customers' lighting satisfaction in eight shopping malls across China at four locations (Shanghai, Nanjing, Langfang, and Harbin) with various climatic, economic, and cultural characteristics [83]. This study indicated a strong association between the presence of daylight and occupant satisfaction ($p < 0.05$). In other words, it showed that people tend to be more satisfied with the lighting conditions they are accustomed to.

Taken together, the studies presented above have demonstrated that people living in the same geographic locations and getting used to experiencing those conditions tend to have similar lighting perceptions and preferences. However, these studies solely considered the lighting conditions that the participants were exposed to and did not involve individual differences resulting from the climatic and cultural diversity of the locations such as ethnic background, lifestyle (how much daylight the individual is exposed to on a typical day), and sociocultural norms.

5.3.3. Previous luminous environment (the luminance environment individuals were recently exposed to)

The term "Zeitgeber" is used as a time giver or synchroniser in the chronobiology field that examines the effects of time on biological events and internal biological clocks. It is considered an external cue that synchronises an organism's biological rhythms to the Earth's 24-hour light and dark cycle. The circadian clock prominently coordinates biochemical, physiological, and behavioural processes; thus, zeitgebers are vital in human biological rhythms. There are two types of zeitgebers: photic and non-photic, and these components are light, atmospheric conditions, medication, temperature, social interactions, exercise, and eating/drinking patterns. Even though each of these components is linked to each other, lighting takes the lead as the most potent cue to synchronise the circadian clock [50].

Lighting as one of the important zeitgebers is perceived only from the retina with the aid of different kinds of photoreceptors: rods, cones, and recently discovered ipRGCs (Intrinsically photosensitive retinal ganglion cells). Several pieces of research showed that rods and cones play a crucial role in the image-forming vision, whereas the ipRGCs are responsible for the non-image-forming vision. This non-image-forming photoreceptive system takes part in the regulation of several functions. However, the impact of lighting depends on the intensity, duration, wavelength, and timing of light exposure [179]. Nevertheless, very little research has directly investigated the effect of the previous luminous environment and its consequent outcomes [180].

The previous luminous environment represents the lighting conditions a subject experienced in a specific period. This period may vary from hours and days to weeks and years. Previous studies have primarily defined prior photic history as the intensity and duration of prior light exposure. They also have demonstrated that the amount of exposed daylight while spending time outside or sitting indoors by a window is significant because prior lighting conditions determine how much melatonin suppresses response to daylight and, ultimately, how we perceive and evaluate lighting conditions. For instance, an individual who spends time outside most of the day may not evaluate daylight conditions as the same as another person who generally spends time indoors, even if they live in the same geographic location providing the exact outdoor illuminance conditions.

Long-term exposure to low light levels might cause higher sensitivity in the rods and may increase the time of light adaptation [181]. A study indicated that exposure to a very dim light level caused significantly more phase shifting response (the move in bedtime and wake-up time) to light (60-70%) rather than a typical room light level exposure [182]. Also, long-term daylight deprivation has a remarkable impact on participants' sleep-wake patterns and retinal sensitivity after seven months without sunlight ($p<0.05$) [169]. This view was also supported by Martin et al., who proved that after a week of increased daytime bright-light exposure, subjects would become less sensitive to light and correspondingly, if they were restricted to the dimmer light, they would become more sensitive to lighting conditions [183]. In this study, researchers demonstrated significantly more melatonin suppression after a week of exposure to relatively dim light than after a week of exposure to long durations (about 4 hr per day) of brighter light. They also showed higher light sensitivity after the dim week compared with the bright week. Likewise, Kawasaki et al. investigated the impact of long-term daylight deprivation for seven months on retinal sensitivity, sleep, and circadian rest-activity cycle [169]. They evaluated participants’ retinal sensitivity changes towards different lighting stimuli and measured the rest-activity cycle using activity watches. After the exposure to lighting conditions for seven months, they found an increase in participants’ retinal sensitivity to blue light, whereas a decrease in circadian rhythm stability and delay of sleep-wake timing during long-term daylight deprivation.

The study design also matters in interpreting the findings because most studies in the literature have limited observation time (mostly a week). However, the amount of daylight exposure for a short period may not significantly impact the participants’ lighting evaluations. For instance, if an individual generally spending time indoors is exposed to high daylight conditions for a week, his internal clock may not be affected (it takes some time to adjust), and his lighting perception may be the same as previous regardless of the exposure time and the outdoor illuminance conditions in the last week. Therefore, prior light history should be considered under the combination of outdoor daylight availability and the subject's lifestyle and preferences for a sufficient time. These studies have shown that the issue of prior light history requires further attention as much as other approaches, and prior light history arising from the previous luminous environment could have a considerable impact on lighting perception as well as sleep-wake patterns, mood, and cognition.

5.3.4. Sociocultural background of individuals

As mentioned earlier, the subjective assessment of the same lighting conditions differs from person to person. The variation in the evaluation of the lighting levels could be based on sociocultural context and, ultimately, values, customs, and traditions rather than acclimatisation to some kind of lighting conditions. Individuals with the same sociocultural background might judge the conditions similarly or have identical behaviour patterns. Hence, they may have common attitudes and perceptions towards daylight conditions.

A long-term survey carried out by Siu-Yu Lau, Gou and Li investigated whether daylight helps to increase the satisfaction of residential buildings in Hong Kong [170]. In contrast to other researchers, they also assessed the human-window interaction considering cultural norms. The study results showed that daylight provision did not dominate domestic window design in high-rise residential buildings in Hong Kong. Cultural beliefs and traditions strongly reflect the people’s values, practices, activities and the level of privacy needed in a given home. From this point of view, other factors such as dining habits, views from the living room, and privacy for the bedroom were more important for the residents because of the sociocultural context. Therefore, in some cultures, lighting may not be a primary need because of the sociocultural context and lifestyle, so their perception and expectations may vary from those living in another community with different habits and lifestyles.

In another study, Korean temporary residents immigrating to the United States found acclimatisation to interior lighting conditions challenging [184]. This situation could also be linked to their sociocultural background and traditions because Koreans culturally value a south-facing house with high daylight illumination levels [185]. Parallelly, another study demonstrated that Koreans preferred high-intensity light differently from Americans. Koreans also stated that bright lighting arouses them more than dim lighting in contrast to Americans [185]. A group of researchers investigated whether participants' skin tone influences their light source colour preferences [186]. For this aim, they divided participants into some groups depending on skin tones, such as European, Asian, Indian, African, and North American. Supporting the previous findings, Asians generally chose light sources with a white colour temperature because whiteness symbolises health in their culture, whereas Europeans with the lightest skin type preferred warm light sources. These studies have demonstrated that Korean people specifically value high-intensity lighting, brightness, and white colour temperature due to their traditions and cultural norms.

From another point of view, individual lifestyle and daily routines could be related to sociocultural background, and therefore behavioural factors that are not mostly accounted for in most studies could affect the perception of lighting quality. For instance, some individuals tend to spend more time outdoors culturally, and their lighting evaluation could vary from those spending mostly indoors due to high levels of light exposure [164].

Taken together, all these studies have indicated that sociocultural background, lifestyle and related perceptual and behavioural patterns could cause inter-individual differences in daylight perception. For this reason, further research should be undertaken, considering both sociocultural and individual variations.

5.3.5. Application of the findings into the thesis

This thesis aims to investigate the impact of cultural background on daylight perception. For this aim, it is essential to define the culture in the lighting environment and develop a methodology for assessment. This systematic review showed that cultural background corresponds to **(1)** the ethnicity and/or physiological characteristics of the individual eyes, **(2)** the area (luminance environment) where people used to live, **(3)** the luminance environment they were recently exposed to and **(4)** the sociocultural background of individuals. From this point of view, a methodology was developed and reported in the following chapter. This methodology consists of a survey asking participants about their ethnicity, the city they spent most of their life, the city they lived in before they came to London and their daylight exposure pattern on a typical day. These questions were derived from the components developed in the systematic review, and their responses were assessed with participants' evaluations of daylight availability on a surface.

5.3.6. Limitations

The most significant limitation of this chapter was the lack of pre-existing literature on this topic, as well as the fact that almost all studies related to culture in the lighting field were evaluated in the context of the visual discomfort glare evaluation of participants. This study was needed because no comprehensive existing study in the literature focuses on the relationship between cultural background and the participants' perception of illuminance levels.

5.4 Summary

This chapter aimed to create a conceptual framework of cultural background in lit environments to investigate an association between cultural background and daylight perception of participants. The review showed that factors thought to be influencing daylight perception in the cultural context have been explored in several ways. It firstly demonstrated that ethnicity and/or physiological properties of individual eyes affect daylight perception and preferences. Secondly, it provided evidence that the participants' residential area influences their daylight perception on the assumption that people living in the same geographical location become accustomed to those conditions and thus perceive daylight conditions similarly. Thirdly, it remarked on the importance of the previous luminance environment and suggested that the prior light history should be considered under the combination of outdoor daylight availability and the subject's lifestyle and preferences for a sufficient time. Lastly, it stated that sociocultural background and possibly related behaviour patterns impact daylight perception within the individual and contextual variability. Together these results provide valuable insights into daylight perception in the cultural context.

This chapter has confirmed the assumption that there are differences in how people perceive and feel about lighting conditions due to their cultural backgrounds with various approaches. It also has remarked on the lack of comprehensive knowledge of this issue regarding the perceived adequacy of illumination for people from different cultural backgrounds. Therefore, a further study focusing more on daylight perception with the combination of the cultural background approaches explained previously is recommended. Future research should further test these components together and separately to investigate which component or combination is more influential on daylight perception.

CHAPTER 6: Investigation of the influence of cultural background on daylight perception

6.1 Introduction

Exposure to daylight has been shown to boost occupants’ visual, task and behavioural performance as well as social interactions [26]. Additionally, daylight enhances the aesthetics of a space and can help to improve the building’s energy efficiency [187]. In this respect, individuals' daylight perception, which represents people's feelings about daylight conditions, as well as their level of satisfaction with daylight conditions, may influence their preferences, expectations, and behaviours. This knowledge could help meet the occupants’ needs and preferences, which in turn help increase occupant satisfaction with the indoor environment and reduce the unnecessary energy consumption of both HVAC and illumination systems in the built environment. However, the reasons for perceiving daylight conditions differently than other individuals require further investigation, and this thesis aims to explore the cultural background as an inter-individual difference in daylight perception.

In previous chapters, the methods for assessing daylight perception were reviewed and concluded that subjective rating and seat preference methods could be used to evaluate daylight perception. Afterwards, the conceptual framework of cultural background in the lit environment needed to be identified to evaluate the inter-individual differences in daylight perception caused by variations in cultural background. The review revealed that factors thought to influence daylight perception in the cultural context have been investigated in a variety of ways. These factors are the ethnicity and/or physiological characteristics of the individual eyes, the area (luminance environment) where people used to live, the luminance environment they were recently exposed to and the sociocultural background of individuals. This chapter, therefore, aims to establish a methodology and report the findings of the study for assessing daylight perception in the context of cultural background, building on the highlighted findings of the previous chapters.

6.2 Methodological approach

6.2.1 General approach

This chapter combined qualitative and quantitative data to understand if an individual's cultural background influences how daylight conditions are perceived. For this purpose, subjective ratings and seat preference methods were used to evaluate daylight perception. In order to assess the participants' subjective responses, they were asked to fill out a semi-structured questionnaire, which included a section for rating the amount of daylight availability at their desks, synchronously quantifying the horizontal illuminance on the desk with an illuminance meter by the researcher. Then, participants' perceptions and actual daylight availability on their desks were compared using the cultural background components reported in **CHAPTER 5**.

Chapters 3 and 4 demonstrated that one of the compelling reasons for students' seat selection is daylight, and a high amount of daylight availability strongly encourages students to select specific seats. Participants in this study who reported being satisfied with their seats were assumed to have chosen those desks because of their daylight availability. In other words, the illuminance levels of the desks chosen by participants who indicated that those were their preferred seats were thought to be an indicator of the participants' level of daylight expectancy from the learning environment. Following that, the horizontal illuminance level of the desks was evaluated using the previously identified cultural background components, as it was done for the subjective response evaluation.

6.2.2 Participants

One hundred ninety-three students (79 male / 109 female) over the age of 20 participated in this study. As seen in **Table 6. 1**, seventy-eight participants (40.4%) described themselves as White, whereas eighty-eight students (45.6%) stated that they came from Asian backgrounds. Only twelve (6.2%), eight (4.1%), and two (1%) participants defined their ethnicities as mixed, other and black, respectively. Almost half of the participants (46.8%) of 193 were overseas students who had spent less than a year in London, which allows an investigation of cultural differences in daylight perception of people from different cultural backgrounds. However, most of the participants consist of White or Asian backgrounds, making it challenging to interpret the perception of people from minority backgrounds. Even though 193 people participated in the study, some did not complete all the questions. As a result, each section will have a different number of participants.

Table 6. 1 *Characteristic of the participant sample*

N = 193	
Gender	**190**
Male	79 (40.9%)
Female	109 (56.5%)
Other	0 (0%)
Prefer not to say	2 (1.1%)
Age	**180**
<20	8 (4.1%)
20-24	88 (45.6%)
25-29	51 (26.4%)
30-34	18 (9.3%)
>35	15 (7.8%)
Time spent in London	**189** (mean:47.4, std:87.6)
<3 months	66 (34%)
3 to 6 months	22 (11.3%)
6 months to a year	3 (1.5%)
More than a year	98 (50.5%)
Ethnicity	**188**
White	78 (40.4%)
Mixed/Multiple ethnic groups	12 (6.2%)
Asian/Asian British	88 (45.6%)
Black/African/Caribbean/Black British	2 (1%)
Other ethnic groups	8 (4.1%)
Area of residence	**194**
London residents	16 (8.2%)
Non-London residents	178 (91.8%)

6.2.3 Field site

The study was carried out at the UCL Bartlett Library, described in detail in Chapter 3, **section 3.3.3**. The library is located on the ground floor of a six-story building. The library has three main study areas; Room 1 contains eight shared desks and four individual cubicles, Room 2 has twelve shared desks and eleven individual desks, and Room 3 has thirty-two shared desks.

6.2.4 Quantification of daylight

In order to evaluate the daylight perception of participants, it was necessary to know how much daylight they were exposed to while participating in the study. For this purpose, the horizontal daylight illuminance was measured with an illuminance meter from the centre of the participants' desks at the start and end of the questionnaire. The average illuminance was then written on the top right of the questionnaire while it was being collected. The KONICA MINOLTA Illuminance meter T-10A (20014862) was used as a data collection instrument to measure horizontal illuminance on the desk, assuming it as individual daylight exposure during the questionnaire.

6.2.5 Study procedure

The researcher created a semi-structured questionnaire that was approved by the Ethical Committee of the University College London, the Bartlett School, Institute of Environmental Design and Engineering. During the week commencing on the 2nd of December 2019, students who had already been studying in the Bartlett library were randomly approached and asked if they were interested in participating in the study. Before beginning the study, the researcher asked if they had any questions about the procedure, and they were given a paper version of the questionnaire if they had no questions. The questionnaire took 10 to 15 minutes to complete.

6.2.6 Questionnaire design

The questionnaire (See **Appendix 5**) was comprised of 18 questions, including multiple answers, a Likert scale, and open-ended questions with some sub-questions. The questionnaire was divided into five sections;

(1) questions (Q1, Q2, Q4) about **demographic information** such as gender, age and ethnicity,

(2) questions (Q3, Q6) about **the geographic location of residence** (the luminance environment where people used to live), such as the length of time spent in London and the most common/most recent place of residence,

(3) questions (Q7, Q9) about **the previous luminous environment** (the luminance environment individuals were recently exposed to), such as the number of regular and free days and time intervals describing their average daylight exposure outdoors on those days,

(4) questions (Q10, Q11, Q12) about **seating preferences** such as the reason for seat selection, willingness to sit at that particular desk and duration of stay and

(5) questions (Q14, Q18) about **daylight perception and satisfaction,** such as evaluation of daylight availability, daylight distribution, glare probability, and overall visual comfort. In order to answer the questions raised in this study, only some sections of the questionnaire were reported.

6.2.7 Assessment methods

The five sections of the questionnaire were evaluated as described below;

- Data obtained from **demographic information** such as gender, age and ethnicity were used directly at baseline.

- Data obtained from **the geographic location of residence** (the luminance environment where people used to live), such as the length of time spent in London and the city where participants spent the majority of their lives and the previous years before arriving in London, was evaluated using the cities' external illuminance levels, as explained in Chapter 6, **section 6.2.7.1.**

- Data obtained from **the previous luminous environment** (the luminance environment individuals were recently exposed to), such as the number of regular and free days and time intervals describing their average daylight exposure outdoors on those days, was assessed using a novel method developed by combining the Munich Chronotype Questionnaire and the Harvard Light Exposure Assessment Questionnaire, as described in Chapter 6, **section 6.2.7.2.**

- Data obtained from **seating preferences** such as the reason for seat selection, willingness to sit at that particular desk and duration of stay was assessed under the assumption that the illuminance levels of the desks chosen by participants who stated that those were their preferred seats (**Figure 6. 1**) represented the participants' level of daylight expectancy. Thus, the impact of cultural background components, identified in the previous chapter, on daylight perception was evaluated while taking into account the preferred desks' horizontal illuminance levels.

11. Is it your preferred seat?
(If it is not your preferred seat, please indicate your best place in the plan drawing in Question 18 with reason)

- ❑ **Yes**, it is my preferred seat.
- ❑ **No**, I tend to sit here whenever possible. (seat place is not important for me)
- ❑ **No**, I sat here because my preferred seat was not available (e.g. someone else was sitting there)

Figure 6. 1 *The question asking participants their seat preference*

- Data obtained from **daylight perception and satisfaction** was evaluated using a unique developed scale based on lighting guidelines that aims to categorise daylighting measurements and assess their sufficiency for comparison with participants' self-reportings, as explained in Chapter 6, **section 6.2.7.3.**

6.2.7.1. Assessment of daylight availability in cities where participants lived

Few researchers put forward that individuals' acclimatisation to specific outdoor daylight conditions may result in differences in their daylight perception, preference, and expectation because exposure to a certain amount of daylight at a specific time has significant effects on human circadian rhythms. Residents in Tel Aviv, for example, where illuminance levels exceed 75,000-lux for approximately 66% of the time, may not have the same daylight expectations as residents in Berlin, where similar illuminance levels are rare.

However, it was impossible to estimate how much daylight individuals were exposed to in the city where they have spent most of their lives and their last year before moving to London without long-term recording using devices that participants were asked to wear, such as wristbands, Daysimeters, and ambulatory circadian monitoring devices. Hence, a novel methodology was created to assess the effect of the geographical location of participants' cities on their daylight perception. In order to achieve this goal, participants were asked in the questionnaire in which cities they spent the majority of their lives and the last years. Following that, **"the median external diffuse horizontal illuminance"** of the cities from which participants came was used as an indicator of daylight availability in their cities. This value was extracted from the cities' standardised climate files to represent the city's typical lighting conditions.

In order to obtain the data on the median external diffuse horizontal illuminance for each city mentioned by participants in the questionnaire, epw. files for each city were downloaded from https://www.energyplus.net/weather. Then, a utility developed by Energyplus was used to convert each epw. files into csv. file formats. Afterwards, each csv. file was opened with Microsoft Excel, and the median of the external diffuse horizontal illuminance was calculated while ignoring zero values. This procedure was repeated 143 times, and all cities' median external diffuse illuminances are listed in **Appendix 6**.

6.2.7.2. Assessment of individuals' daylight exposure in London

An individual's daylight exposure is calculated in the literature using circadian light metres such as wearables and smartwatches. Circadian light metres, however, have some limitations due to cloth coverage or incorrect usage, and they are not practical for assessing the light exposure of participants in large-scale studies. At this point, researchers can estimate the amount of light exposure of participants using the Morningness-Eveningness Questionnaire (MEQ), the Harvard Light Exposure Assessment Questionnaire (H-LEA), and the Munich Chronotype Questionnaire (MCQ). Although the Morningness-Eveningness Questionnaire is the most widely used tool for assessing light exposure, the Munich Chronotype Questionnaire is one of those that can most accurately predict photic and circadian data from physical measurements using the scores on self-reported light exposure [194]. As a result of its reliability, the developed methodology in this study to assess individuals' daylight exposure in the last four weeks was adapted from the light exposure question in MCQ (**Figure 6. 2**).

I have a regular work schedule (this includes being, for example, a housewife or househusband):

Yes ☐ I work on 1☐ 2☐ 3☐ 4☐ 5☐ 6☐ 7☐ day(s) per week.

No ☐

Is your answer "*Yes, on 7 days*" or "*No*", please consider if your sleep times may <u>nonetheless</u> differ between regular 'workdays' and 'weekend days' and fill out the MCTQ in this respect.

On average, I spend the following amount of time outdoors in daylight (without a roof above my head):

on workdays: _____ hours _____ minutes

on free days: _____ hours _____ minutes

Figure 6. 2 *The light exposure question in the Munich Chronotype Questionnaire (MCQ)*

The total exposed light exposure in the Munich Chronotype Questionnaire (MCQ) is expressed in **Equation 4**, considering only the exposed number of hours. On the other hand, the photometric intensity of light is as important as the duration of light exposure. As a result, the intensity of daylight and time spent outdoors as exposed to daylight had to be considered together while considering the daylight exposure of participants in London prior to the study against the traditional methods that consider only the duration of exposure.

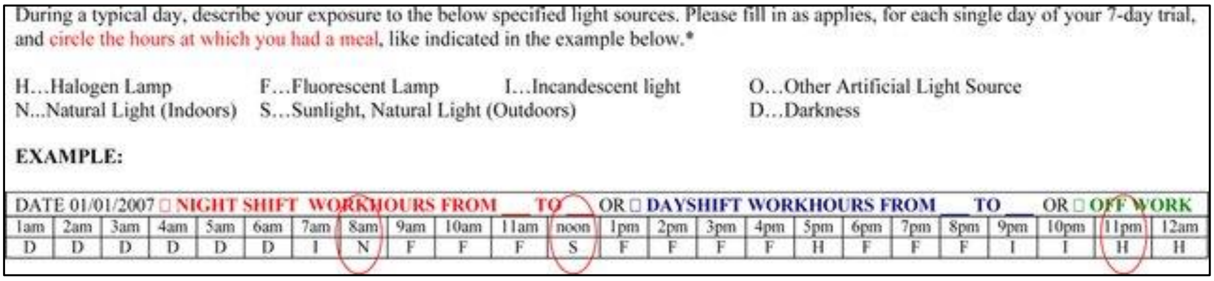
Equation 4 *Traditional method for the calculation of individuals' light exposure*

$$LE = (LEw\ x\ WD\ +\ LEf\ x\ FD)/7$$

where

LE= Light exposure
LE_w = Workday light exposure
W_D = Number of workdays per week
LE_f = Free daylight exposure
F_D = Number of free days per week

In order to develop a methodology for assessing participants' daylight exposure considering both the intensity and duration of daylight, it was benefitted from the way of questioning in the Harvard Light Exposure Assessment Questionnaire. Participants are asked to record the light source(s) they were exposed to hourly for seven consecutive days in Harvard Light Exposure Assessment Questionnaire, as shown in **Figure 6. 3**.



During a typical day, describe your exposure to the below specified light sources. Please fill in as applies, for each single day of your 7-day trial, and circle the hours at which you had a meal, like indicated in the example below.*

H…Halogen Lamp F…Fluorescent Lamp I…Incandescent light O…Other Artificial Light Source
N...Natural Light (Indoors) S…Sunlight, Natural Light (Outdoors) D…Darkness

EXAMPLE:

DATE 01/01/2007 ☐ NIGHT SHIFT WORKHOURS FROM __ TO __ OR ☐ DAYSHIFT WORKHOURS FROM __ TO __ OR ☐ OFF WORK

1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	noon	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm	12am
D	D	D	D	D	D	I	N	F	F	F	S	F	F	F	F	H	F	F	F	I	I	H	H

Figure 6. 3 *Light exposure question from the Harvard Light Exposure Assessment Questionnaire*

From this point of view, the light exposure question in this study was derived from the calculation method used in the Munich Chronotype Questionnaire and the questioning style in the Harvard Light Exposure Assessment Questionnaire. As shown in **Figure 6. 4**, participants were asked to indicate natural light exposure during a typical day in the last four weeks without a roof above the head. The time interval of the scale was defined by the sunrise and sunset times in the last four weeks. In other words, the earliest sunrise time in London was accepted as the starting time, and the latest sunset time was accepted as the ending time on the scale.

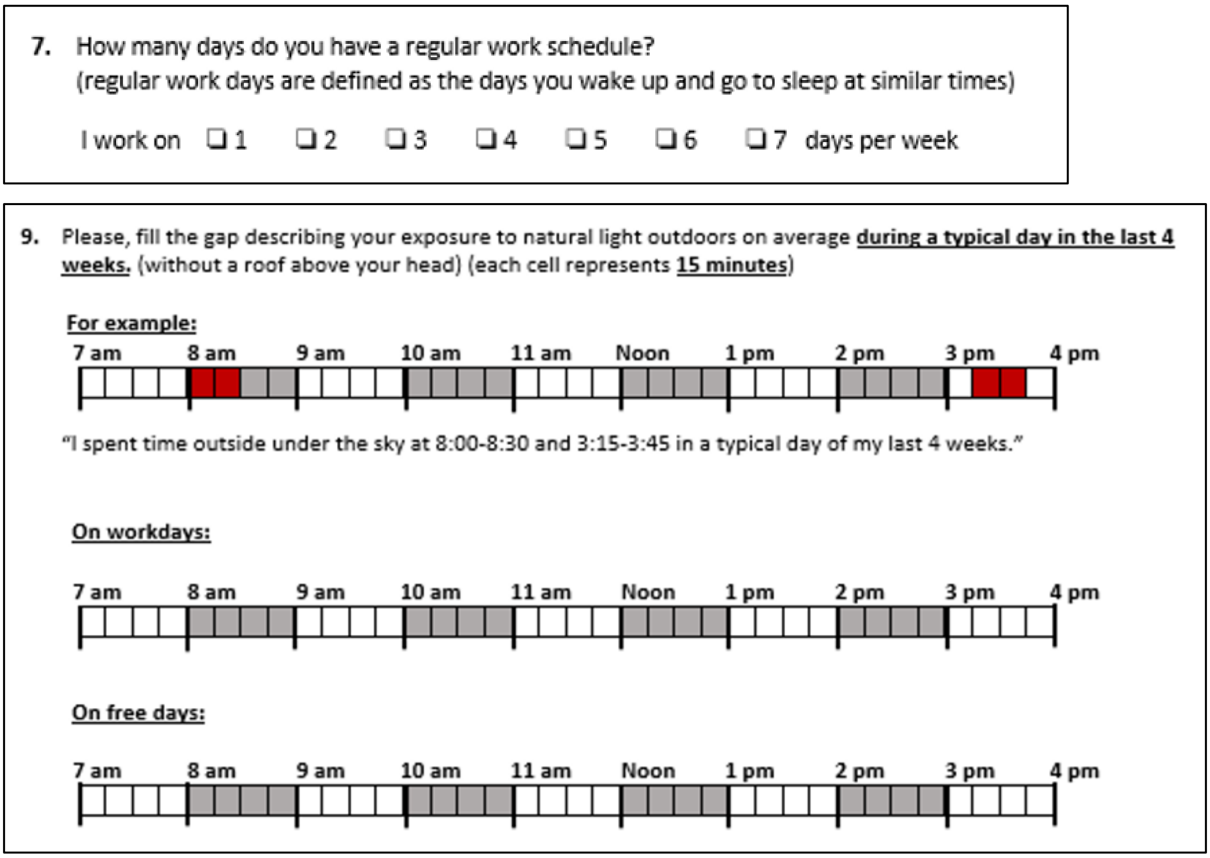


***Figure 6. 4** Light exposure question in this study*

However, the question of how the daylight intensity would be calculated in the specified time intervals indicated by participants remained. In order to answer this question, the external illuminance in London at 15-minute intervals had first to be defined. Then, the intensity of daylight at specific time intervals would be calculated based on participants' responses.

In order to obtain the external illuminance in London at 15-minute intervals, hourly weather pattern information data for London obtained from London St. James Park weather station was downloaded via WEA file from http://climate.onebuilding.org/. The file was then opened in Notepad, and the entire contents were pasted into Microsoft Excel using the Excel Import Wizard. Following that, data from 6 November 2019 to 4 December 2019 (the four weeks preceding the study) was imported into another Excel file with date, time, direct irradiance, and diffuse irradiance values. The external illuminance value had to be calculated using the direct and diffuse irradiance values. As mentioned in EN 17037, the irradiance values can be multiplied by luminous efficacy (110 lm/W) to obtain illuminance values for each hour (**Equation 5**).

Equation 5 *Illuminance calculation method suggested in EN 17037*

$$\frac{Direct\ irradiance + Diffuse\ irradiance}{2}\left({}^{kWh}/_{m^2}\right) \times\ 110\,{}^{lm}/_{W} = Illuminance\ (lux)$$

From this point of view, the average direct and diffuse irradiance values between 6 November 2019 and 4 December 2019 were calculated on an hourly basis; then, they were divided by two and multiplied by 110 lm/W as suggested by the above equation. At the end of this process, hourly basis illuminances for the last four weeks on average were obtained as illustrated in the below table (**Table 6. 2**)

Table 6. 2 *Hourly illuminance values in London over the last four weeks*

Time period	Average direct irradiance	Average diffuse irradiance	All average	External illuminance
00:00- 01:00	0.00	0.00	0.00	0.00
01:00- 02:00	0.00	0.00	0.00	0.00
02:00- 03:00	0.00	0.00	0.00	0.00
03:00- 04:00	0.00	0.00	0.00	0.00
04:00- 05:00	0.00	0.00	0.00	0.00
05:00- 06:00	0.00	0.00	0.00	0.00
06:00- 07:00	0.00	0.00	0.00	0.00
07:00- 08:00	0.00	3.96	1.98	208.13
08:00- 09:00	40.93	46.68	43.80	4599.38
09:00- 10:00	173.50	85.64	129.57	13605.00
10:00- 11:00	258.21	114.00	186.11	19541.25
11:00- 12:00	289.68	129.46	209.57	22005.00
12:00- 13:00	276.11	123.93	200.02	21001.88
13:00- 14:00	228.79	105.61	167.20	17555.63
14:00- 15:00	113.68	73.89	93.79	9847.50
15:00- 16:00	6.86	24.32	15.59	1636.88
16:00- 17:00	0.00	0.00	0.00	0.00
17:00- 18:00	0.00	0.00	0.00	0.00
18:00- 19:00	0.00	0.00	0.00	0.00
19:00- 20:00	0.00	0.00	0.00	0.00
20:00- 21:00	0.00	0.00	0.00	0.00
21:00- 22:00	0.00	0.00	0.00	0.00
22:00- 23:00	0.00	0.00	0.00	0.00
23:00- 00:00	0.00	0.00	0.00	0.00

However, participants in this study were asked to indicate natural light exposure at 15-minute intervals. For this reason, the hourly external illuminances needed to be divided into 15-minute intervals to specify the exact amount of daylight they were exposed to. For this purpose, Matlab software was used to integrate a set of illuminance level data and corresponding time data to approximate the amount of daylight exposure, and the integration was plotted in **Figure 6. 5**. The integral area under the curve in 15 minutes was calculated and reported in **Figure 6. 6.**

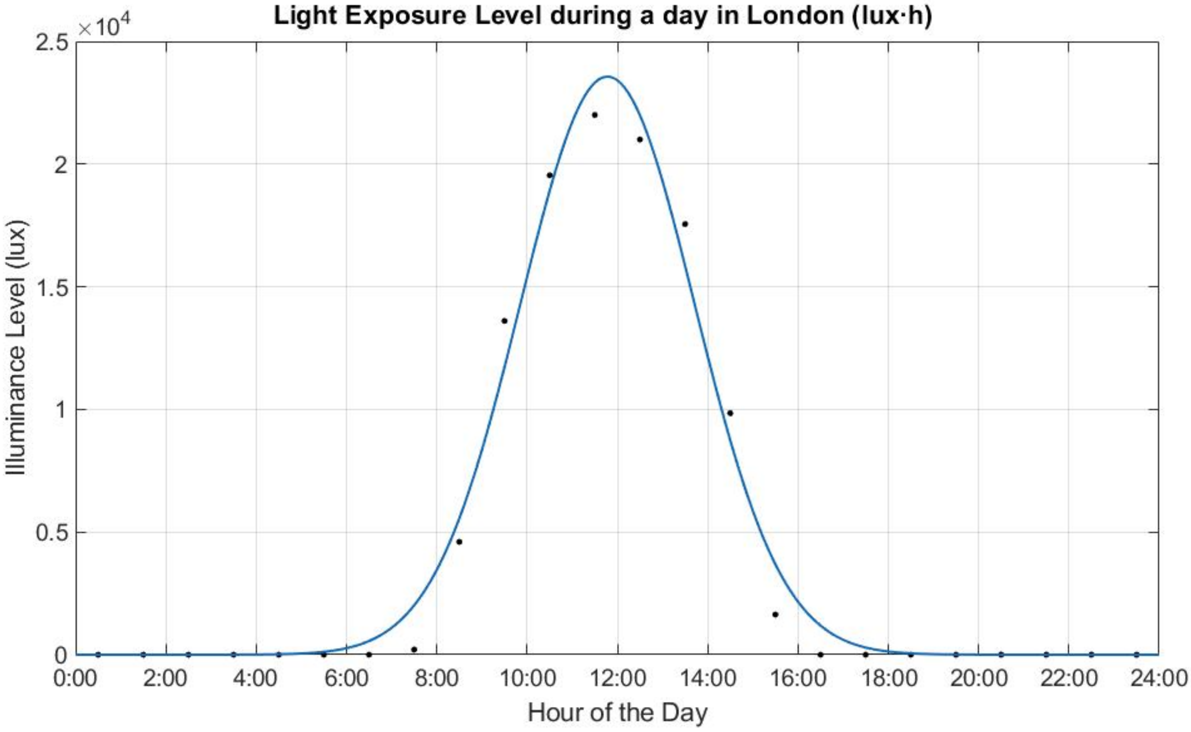


Figure 6. 5 *Integration of hourly external illuminances data and corresponding time data to approximate the amount of daylight exposure*

07:00- 07:15	322.90	11:30- 11:45	5869.46
07:15- 07:30	437.39	11:45- 12:00	5881.27
07:30- 07:45	582.63	**12:00- 12:15**	5795.22
07:45- 08:00	763.22	12:15- 12:30	5615.59
08:00- 08:15	983.17	12:30- 12:45	5351.14
08:15- 08:30	1245.47	12:45- 13:00	5014.46
08:30- 08:45	1551.55	**13:00- 13:15**	4620.92
08:45- 09:00	1900.75	13:15- 13:30	4187.53
09:00- 09:15	2289.87	13:30- 13:45	3731.77
09:15- 09:30	2712.82	13:45- 14:00	3270.37
09:30- 09:45	3160.52	**14:00- 14:15**	2818.42
09:45- 10:00	3620.94	14:15- 14:30	2388.58
10:00- 10:15	4079.54	14:30- 14:45	1990.68
10:15- 10:30	4519.88	14:45- 15:00	1631.50
10:30- 10:45	4924.57	**15:00- 15:15**	1314.93
10:45- 11:00	5276.39	15:15- 15:30	1042.17
11:00- 11:15	5559.44	15:30- 15:45	812.28
11:15- 11:30	5760.38	15:45- 16:00	622.58

Figure 6. 6 *External illuminance in London at 15-minute time intervals between 6 November 2019 and 4 December 2019*

After identifying external illuminance for every 15 minutes in London over the previous four weeks, individuals' daylight exposures were calculated by summing the external illuminances for their specified time intervals indicated in the questionnaire for regular and free days separately. Individuals' total daylight exposure was then calculated using the formula shown in **Equation 5.**

Figure 6. 7 shows a linear regression between the developed calculation method based on both the intensity and duration of daylight exposure and the traditional calculation method based solely on the duration of daylight exposure ($p<0.05$). As can be seen, the results obtained using the traditional method are accounted for 44.9% of the explained variability in the developed method. Although the traditional approach is widely used in the literature, it is strongly recommended to use the developed methodology that takes into account the intensity of daylight as well.

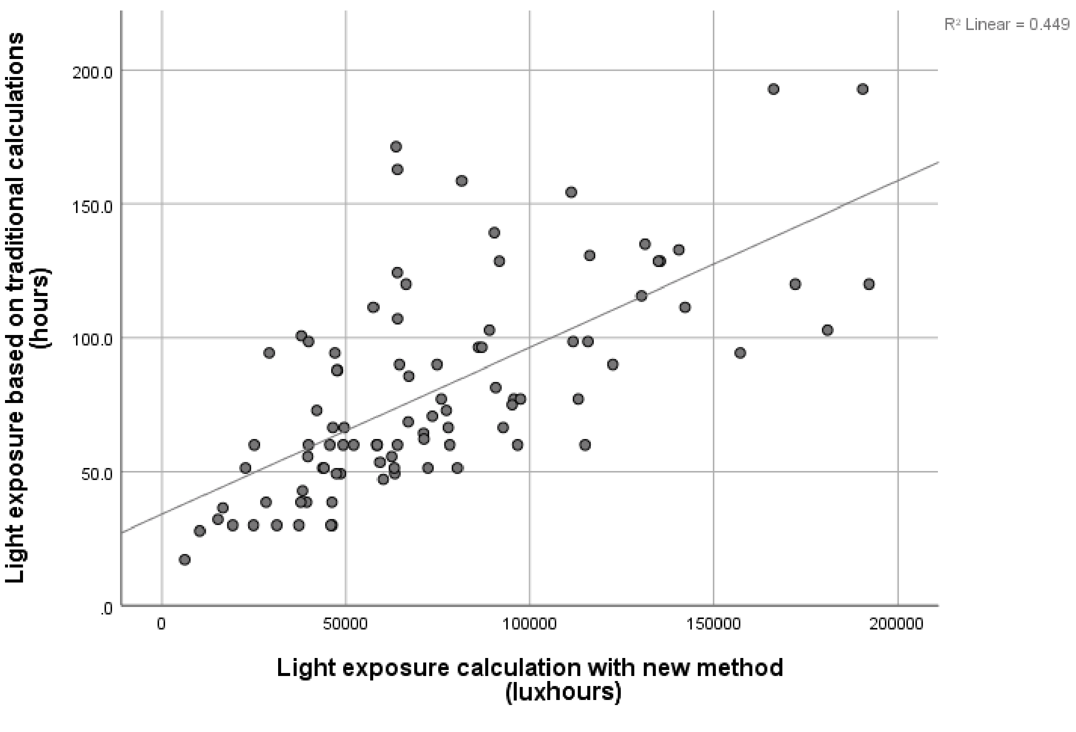
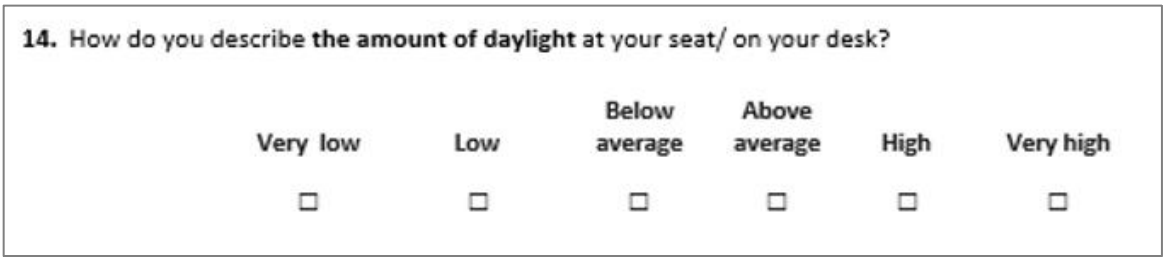


Figure 6. 7 *Comparison between the developed method and the traditional method for assessment of light exposure*

6.2.7.3. Assessment of individuals' daylight perception

The self-reported illuminance levels of the 193 participants were compared to the measured illuminance levels on their desks to investigate inter-individual differences in daylight perception. For this aim, participants were asked to rate the adequacy of daylight availability on the desk they were already using on a scale ranging from very low to very high (**Figure 6. 8**)


14. How do you describe **the amount of daylight** at your seat/ on your desk?

Very low ☐ Low ☐ Below average ☐ Above average ☐ High ☐ Very high ☐

Figure 6. 8 *The question that asked participants to describe the lighting conditions at their desk*

The researcher used an illuminance meter to measure the current illuminance levels at participants' desks. However, the measurements needed to be classified in order to determine their sufficiency and assess participants' subjective responses based on them. Therefore, a scale was developed based on the lighting guidelines because there was no developed assessment scale in the literature to take as a reference until now (**Figure 6. 9**)

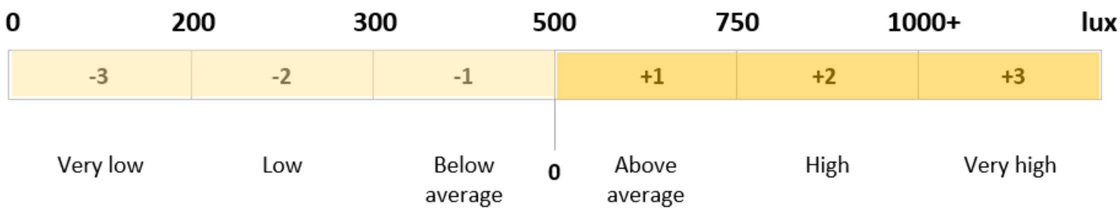


Figure 6. 9 *The developed scale for the classification of measured illuminance levels*

The scale was developed using thresholds from lighting guidelines. For instance, the EN 12464 Light and Lighting recommends lighting levels for library reading rooms between 300-500 lux to allow for proper reading and writing, with 500 lux being the optimum. As a result, 500 lux was defined as the optimum level in this study and designated as zero. Also, less than 200 lux was not acceptable for reading and writing activities; hence this range was designated as very low (-3). The middle range (200-300 lux) was designated as low because it is considered as acceptable for reading and writing but does not provide the optimum lighting conditions for libraries.

On the other hand, more detailed works that require significantly more lighting in places such as laboratory classrooms require lighting between 500 and 750 lux; thus, this range was designated as +1. Furthermore, some places that require extra attention, such as operating rooms, require more than 1000 lux of light. As a result, the range above 1000 lux was defined as very high (+3), and the range in-betweener (750-1000 lux) was defined as high (+2).

In general, developed scales must be validated using data collected by other researchers. However, verifying the proposed scale was impossible because this topic was quite unique, and there was no collected data to share until now. As a result, in order to validate the scale, the results obtained using the scale were compared to those obtained using the quartiles method, which involved randomly dividing the illuminance measurements into quantiles. According to the findings of the analysis, this scale was found to be reliable in assessing the relationship between individuals' daylight perception and illuminance levels ($p=0.05$).

6.2.8 Method of analysis

For all statistical analyses in this study, data from participant responses, daylight spot measurements, and external diffuse horizontal illuminance data from the EnergyPlus website were analysed using the software package SPSS 20.0. Univariate descriptive statistics (response frequencies, means, and standard deviations) were computed for each variable in the questionnaire and daylight measurements. As needed, the data were checked for normality using analytical Kolmogorov-Smirnov/Shapiro-Wilk tests. Linear regression was used to analyse the relationship between the external illuminance of the city where participants spent most of their lives (continuous) and last years (continuous), and daylight exposure in London prior to the study (continuous), the length of time duration in London (continuous), as input or explanatory variables, and daylight availability at the desk chosen (continuous) as an output. Ordinal regression was used to determine if any variable influences the daylight perception of participants alone or altogether. Binary logistic regression was also used to investigate the impact of various factors on participants' agreement between self-reported and measured lighting levels. Additionally, an ANOVA test was used to determine differences in daylight availability of the desks chosen by people from various groups.

6.3 Results and Discussion

6.3.1. Agreement between self-reported and measured illuminance levels using different methods

In **CHAPTER 3**, it was demonstrated that subjective rating and seat preference methods could be used to assess daylight perception. Therefore, the purpose of this chapter was to investigate the impact of participants' cultural backgrounds on their daylight perception using the subjective rating and seat preference methods, taking into account the cultural background components identified in **CHAPTER 5** using the subjective rating and seat preference methods.

6.3.1.1. Subjective ratings

CHAPTER 3 showed the suitability of the subjective rating method for assessing daylight perception of participants, demonstrating a strong relationship between daylight availability and subjective statements of participants. Even though the same question was used to assess participants' perceptions of daylight in this study, the contribution of daylight availability to their subjective statement of daylight was less significant than in the previous study (p=0.06). As shown in **Table 6. 3**, this could be due to differences in sample characteristics, study procedure, participant acclimatisation to lighting conditions, method of quantifying daylight availability, and the contribution of electric light to their daylight perception.

Table 6. 3 *Comparison of studies using the subjective rating method*

Differences	The study mentioned in Chapter 3	The study mentioned in Chapter 6
Sample size	50 participants	193 participants
Participants' activity	Students were brought all together to the library, asked to complete a questionnaire before the experiment and undertake a set of tasks while going around the library.	Students who had already been studying in the Bartlett library were randomly approached and asked if they were interested in participating in the study.
Acclimatization to lighting conditions	Participants were instructed to walk around the library, choose the best and worst seats, and then assess the daylight availability on the best seat selection without having to sit down. As a result, they assessed the lighting conditions without acclimatisation.	Participants had been present for a while for various reasons in the library. As a result, some of them may have become accustomed to the lighting conditions at their desks.
Type of participants	MSc students from the same department were requested to participate in the study after their lecture	Students from all educational backgrounds were chosen at random in the Bartlett Library
Quantification of daylight	Parametric modelling and daylight simulations were used to get information about daylight availability, and they were validated against spot measurements with the daylight availability at a specific day and time	The horizontal daylight illuminance was measured with an illuminance meter from the centre of the participants' desks at the start and end of the questionnaire. The average illuminance was then written on the top right of the questionnaire while it was being collected
Quantification of daylight perception	The same question was used to evaluate daylight perception of participants ranging from very low to very high	

Contribution of the electric light	The daylight simulation results solely represented daylight availability on the desk at the time when participants chose the desk	The horizontal daylight illuminance measured with an illuminance meter included electric and daylighting. Although the contribution of electric light to each desk was nearly identical, it could affect participants' perception of daylight
The relationship between daylight availability and subjective statements of participants	The contribution of horizontal illuminance on the desk obtained from daylight simulations significantly affected the subjective assessment of daylight, p =0.002.	Although there is still a nearly strong relationship between daylight availability and participants' subjective statements on daylight, daylight was less significant on participants' perceptions than compared to study in Chapter 3 (p=0.06)

In order to investigate the inter-individual differences in daylight perception, it was necessary to assess the participants' self-reportings with the measured daylight availability. For this aim, participants were asked to assess the lighting conditions on their desks ranging from very low to very high (See Question 14 in **Appendix 5**). Unlike the previous study shown in Chapter 3, this study also aimed to improve the assessment method for daylight perception of participants. Correspondingly, a scale (See in Chapter 6, **section 6.2.7.3**) was developed to categorise the measured lighting levels and assess the lighting levels' sufficiency based on the thresholds given by guidelines. The developed scale also helps ease the interpretation and presentation of the findings.

__Table 6. 4__ The agreement between self-reported and measured illuminance levels

N=185		Illuminance level on the desk: Very low	Low	Below average	Above average	High	Very high	Total
Participants' perceptions	**Very low**	1	1	7	2	1	0	12
	Low	0	2	13	9	4	0	28
	Below average	1	3	15	11	5	3	38
	Above average	4	5	26	31	6	6	78
	High	0	1	12	6	4	2	25
	Very high	0	0	3	0	0	1	4
	Total	6	12	76	59	20	12	185

	Value	**Approximate Significance (p-value)**
Measure of Agreement (Kappa)	0.060	0.113
N of Valid Cases	185	

Colour	Meaning
Dark orange	Strongly agreement
Light orange	Agreement
White	Disagreement

As seen in **Table 6. 4**, in this study, 42% and 20% of those who participated described daylight conditions as above average and below average, respectively. Less than a fifth of those who responded (13%) indicated that daylight conditions on their desk were high, whereas 14.5% stated that the perceived daylight level was low. Only 16 people described the daylight conditions as very low (6%) and very high (2%).

Table 6. 4 represents the participants' perceptions of daylight conditions versus the measured illuminance conditions. *Highlighted cells with dark orange colour demonstrate how many people perceived the conditions in line with the daylight measurements. However, human perception of something like fluctuating lighting does not always provide an absolute value, as it is a subjective way of feeling. Therefore, participants may find it difficult to differentiate a daylight measurement*

from a range of values, and they may describe it as lower or higher ranges of illuminances. As a result, in this study, people who perceived conditions close to the range of actual measurements (cells with light oranges) were also considered to agree with the measured lighting conditions. White cells were also used to represent the rest of the people who perceived daylight conditions differently from actual measurements.

As shown in the table, 54 of the participants perceived daylight conditions that matched the actual measurements, and 68 of them described daylight conditions in a range very close to actual daylight measurements. However, 63 participants perceived daylight conditions as slightly or significantly different from actual measurements. In total, 66% of participants perceived daylight conditions that were exactly or very close to the actual daylight measurements; however, why the remaining participants perceived differently and whether the cultural background is a factor in the variation remains unknown. In summary, this table demonstrated that individuals do not always perceive daylight conditions as occurring. Individual differences could impact this variation, and this situation highlights the need and potential contribution of this study.

As shown in the table, while some participants described daylight conditions that matched the illuminance measurements, others perceived conditions that were lower or higher than the actual measurements. In this study, people who described the conditions as lower and higher were labelled as *underperceived* and *overperceived*, respectively. In order to investigate if people are more likely to describe daylight conditions as lower or higher than actual measurements, a McNemar test was conducted. It showed no discernible tendency in individuals' perception to underperceive or overperceive daylight conditions, OR=0.87 (95% CI 0.61-1.25), ($p=0.48$).

6.3.1.2. Seat preference

Previous research on seat preference presented in Chapter 3 was conducted with people who had the opportunity to choose their seat, and the study results showed that daylight was the most dominant reason when selecting the best desks in the library, followed by privacy, outdoor view and quietness, respectively. Following that, the study presented in Chapter 4 that used data obtained from monitor sensors revealed that a high level of daylight strongly encourages students to select a seat. From this point of view, it was interpreted that daylight availability at a specific desk mostly represents individuals' expectations of daylight when they have a chance to choose.

This study was conducted with randomly approached students who had already been studying in the Bartlett library and asked if they were interested in participating in the study. Participants were asked in the questionnaire why they chose their seats, whether they were willing to sit at that particular desk, and how long they had been studying at that desk. In this study, 72 students (37%) stated that their seat was their preferred seat, whereas 47 (24%) indicated that they selected those desks due to reasons beyond their control, such as no availability of their preferred seats. Seventy of them (36%) also stated that they tend to sit wherever possible and seat place is not important for them.

Similar to previous findings, this study found that daylight (34%) was the most common reason for student seat selection, followed by outdoor view (20%), privacy (17%), and quietness (13%), respectively. However, due to the lack of available desks in this study, all students could not select their preferred desks. Therefore, the illuminance levels of the desks chosen by participants who indicated they preferred those seats were thought to be an indicator of the participants' level of daylight expectancy in the learning environment. Following that, the horizontal illuminance level of the desks chosen by participants who reported being satisfied with their seats was evaluated using the previously identified cultural background components, in the same way, that the subjective ratings were evaluated.

In sum, this chapter used subjective ratings and seat preference methods to evaluate the agreement between self-reporting and measured illuminance levels at the desks chosen by students. As previously stated, 66% of participants perceived daylight conditions that were exactly or very close to the actual daylight measurements; however, why the remaining participants perceived differently and whether the cultural background is a factor in the variation remains unknown. Therefore, this analysis focused on the individuals who disagree with the actual measurements and the reasons, in addition to the general assessment of the impact of various factors on how people perceive daylight.

6.3.2. Ethnicity and genetic origin

The systematic review presented in **CHAPTER 5** pointed out the differences in daylight perception and preferences resulting from ethnicity and/or individual eyes' physiological properties.

6.3.3.1. Ethnicity

Method 1: Subjective ratings

Participants were asked to describe the amount of daylight on their desks using a scale ranging from very low to very high, and their responses were evaluated using illuminance measurements taken concurrently with the questionnaire. Following that, the relationship between self-reported and measured illuminances was evaluated based on the ethnic background of the participants.

Within the context of individuals' ethnic backgrounds, **Table 6. 5** shows the proportion of people who perceive daylight conditions that strongly agree, agree and disagree with the measurements. As previously stated, people who perceived conditions close to the range of actual measurements (showing agreement ones) were also considered to agree with the measured lighting conditions. Thus, **Table 6. 6** displays those who strongly agree and agree together in opposition to those who disagree.

As can be seen, participants in this study are primarily from White or Asian backgrounds, and a higher proportion of people from the Asian background (37.5%) described daylight conditions differently from measurements compared to Whites (31.5%). The highest proportion of people describing daylight conditions differently belongs to individuals from black backgrounds (100%); however, they were only two people, and it could not be a proper way to compare them with Whites and Asians due to the minority in this study. A binary logistic regression was carried out to understand if the ethnic backgrounds of participants influence their daylight perception. The results showed no relationship between how people from different ethnic backgrounds perceive daylight conditions and how much daylight is available (p= 0.12).

Table 6. 5 *Comparison of differences in strongly agreeing, agreeing, and disagreeing with self-reported and measured daylight availability by ethnicity*

N=183		Ethnicity					
		White	**Mixed**	**Asian**	**Black**	**Other**	**Total**
Agreement	**Strongly agreement** in self-reporting and measurements	24 (33%)	2 (17%)	25 (28%)	0 (0%)	3 (37.5%)	54 (29.5%)
	Agreement in self-reporting and measurements	26 (36%)	7 (58%)	30 (34%)	0 (0%)	4 (50%)	67 (37%)
	Disagreement in self-reporting and measurements	23 (31.5%)	3 (25%)	33 (37.5%)	2 (100%)	1 (12.5%)	62 (34%)
	Total	73	12	88	2	8	183

Table 6. 6 *Comparison of differences in agreeing and disagreeing with self-reported and measured daylight availability by ethnicity*

N=183		Ethnicity					
		White	**Mixed**	**Asian**	**Black**	**Other**	**Total**
Agreement	**Agreement** in self-reporting and measurements	50 (68.5%)	9 (75%)	55 (62.5%)	0 (0%)	7 (87.5%)	121 (66%)
	Disagreement in self-reporting and measurements	23 (31.5%)	3 (25%)	33 (37.5%)	2 (100%)	1 (12.5%)	62 (34%)
	Total	73	12	88	2	8	183

As previously mentioned, some participants perceived daylight conditions that matched the actual measurements, and some described daylight conditions in a range very close to actual daylight measurements. However, some perceived daylight conditions as slightly or significantly different from actual measurements. It is unclear why the remaining participants perceived daylight availability differently and whether or not cultural background played a role in the variation. **Table 6. 7** shows the tendency in daylight perception of people who disagree with actual measurements. In this analysis, people who described the conditions as lower and higher were named for underperceived and overperceived, respectively.

A considerable amount of the Asian participants (64%) perceived the daylight conditions as lower than actual measurements, while almost half of the White participants described conditions as higher (52%). This finding is supported by previous research showing that Asian people value high daylight illumination levels and feel more comfortable with high glare levels of luminance compared to people from other ethnic backgrounds. A binary logistic regression was conducted to investigate if people who disagree with actual measurements perceive differently due to their ethnic backgrounds. It was found that the differences in their perceptions are not related to their varied ethnic backgrounds (p=0.62).

Table 6. 7 *Tendency in daylight perception of people who disagree with actual measurements by ethnicity*

N=62		Ethnicity					
		White	**Mixed**	**Asian**	**Black**	**Other**	**Total**
Perception accuracy	**Underperceived** of measured daylight availability	11 (48%)	2 (67%)	21 (64%)	1 (50%)	1 (100%)	36 (58%)
	Overperceived of measured daylight availability	12 (52%)	1 (33%)	12 (36%)	1 (50%)	0 (0%)	26 (42%)
	Total	23	3	33	2	1	62

Furthermore, another logistic regression was carried out to investigate whether the likelihood of underperceiving and overperceiving daylight conditions varies depending on participants' ethnic backgrounds. As seen in **Table 6. 8**, the likelihood of perceiving daylight conditions differs significantly depending on whether participants are from White or Asian backgrounds (p=0.04). In other words, Asians are twice more likely to underpredict (perceive daylight conditions lower than actual measurements) than White participants. However, no evidence of a significant likelihood of overperceiving daylight conditions depending on ethnicity was found (**Table 6. 9**).

Table 6. 8 *The likelihood of underperceiving daylight conditions by people from various ethnic backgrounds*

	Underprediction of objectively measured daylight availability	**B**	**Standard Error (SE)**	**Significance (p)**	**Exp (B)**
Ethnicity	White			0.339	
	Mixed	0.59	0.64	0.357	1.80
	Asian	0.70	0.33	0.038	**2.00**
	Black	0.93	1.44	0.520	2.52
	Other	0.41	0.77	0.592	1.51

Reference category: Whites

Table 6. 9 *The likelihood of overperceiving daylight conditions by people from various ethnic backgrounds*

	Overprediction of objectively measured daylight availability	**B**	**Standard Error (SE)**	**Significance (p)**	**Exp (B)**
Ethnicity	White			.488	
	Mixed	0.103	.632	.871	1.11
	Asian	-0.541	.338	.109	0.58
	Black	0.439	1.434	.759	1.55
	Other	-0.659	.851	.438	0.52

Reference category: Whites

Method 2: Seat preference

Previous findings (Chapters 3&4) showed that daylight is one of the compelling reasons for students' seat selection and a high amount of daylight availability strongly encourages students to select specific seats. Therefore, in this study, participants who reported being satisfied with their seats (See Chapter 6, **section 6.2.6**) were considered as they selected those desks because of daylight availability; namely, the level of daylight that students expect from the indoor environment is represented by the availability of daylight at the chosen desk by participants who indicated that they were happy with their seats.

Table 6. 10 displays the mean of daylight availability at the seats of participants from various ethnic backgrounds who stated that they were satisfied with their seats. An ANOVA test was used to determine differences in daylight availability of the desks chosen by people who were satisfied with them. However, no significant relationship was found between the mean of daylight availability at the seat of people from different ethnic backgrounds (p=0.71). However, as seen in the table, daylight availability of the seats selected by people from Asian backgrounds is slightly higher than Whites, as supported by previous findings from the subjective statement method.

Table 6. 10 *The mean of daylight availability on desks chosen by participants from various ethnic backgrounds who reported being satisfied with their seats*

		Mean of daylight availability on the desk (lux)	**Std deviation** (lux)
Ethnicity	**White**	507.1	182.3
	Mixed	548.0	88.5
	Asian	583.3	365.9
	Black	240.0	-
	Other	428.0	-
	Total	548.6	303.0

Lastly, an ordinal regression was performed to determine whether there is a relationship between self-reported and measured illuminance levels of the desks based on the ethnic backgrounds of the participants (**Table 6. 11**). A slightly significant association was found between the self-reported and measured daylight availability depending on the participants' ethnic backgrounds (p=0.08).

Table 6. 11 *Agreement between self-reported and measured illuminance levels on desks by ethnicity*

Ethnicity		The mean of horizontal illuminance on the desk (lux)						
		White	**Mixed**	**Asian**	**Black**	**Other**	**Total**	**p-value**
Self-reporting of participants	**Very low**	496.0	612.0	341.3	-	-	425.1	0.08
	Low	537.0	325.0	511.5	-	437.7	490.1	0.42
	Below average	558.6	-	590.7	-	320.0	570.9	0.51
	Above average	520.6	469.2	573.9	777.5	456.0	545.7	<0.01
	High	588.4	373.0	708.2	-	-	622.9	<0.01
	Very high	448.5	-	384.0	-	1170.0	612.7	0.45
	Total	540.0	448.9	561.9	777.5	521.4	546.8	0.49

6.3.3.2. Genetic origin

Previous research found that genetics largely determines the physiological properties of the eyes. Hence, people with similar genetic backgrounds who live in the same country have generally similar physiological properties of the eyes. It is critical because physiological properties of the eyes, such as shape and colour, play a role in determining the human vision and colour perception. As a result, people with similar eye properties may perceive daylight conditions similarly. However, a questionnaire could not be used to assess the participants' eye properties, and the impact of eye properties on individuals' daylight perception is beyond the scope of this study. For future research, it is highly recommended that a study be conducted in collaboration with researchers from medical and/or genetic backgrounds to investigate how participants' genetic origin influences their perception of daylight.

6.3.3. The geographic location of residence

As stated previously, subjective lighting assessments in the same environment are not often consistent. This might result from the acclimatisation to present outdoor daylight conditions. However, it may not always be possible to accurately monitor the long-term daylight exposure of individuals without devices that participants were asked to wear, such as wristbands, Daysimeters, and ambulatory circadian monitoring devices. Hence, a novel methodology was created in this study to assess the effect of long-term daylight exposure on participants' daylight perception considering the median external diffuse horizontal illuminances of the cities where they have spent time for most of their life and the city where they have been in the last year before coming to London.

Table 6. 12 shows the range of the median external diffuse horizontal illuminances of the cities reported by students where they spent most of their life and the last year. The city with the minimum external illuminance where they have spent most of their life is Urumqi, Xinjiang (9127 lux), and the city with the minimum external illuminance where they spent last year is Stockholm, Sweden (12349 lux). Both cities with the maximum external illuminance belong to a student from Bogota, Colombia (29531 lux). The list of external illuminances of all cities reported by students can be found in **Appendix 6**.

Table 6. 12 *Descriptive statistics on the median external diffuse horizontal illuminance of the cities where students have spent time most of their life and the last year*

	Number of cases	**Minimum external illuminance** (lux)	**Maximum external illuminance** (lux)	**Mean of external illuminance** (lux)	**Std deviation** (lux)
The city where participants spent the **majority of their lives**	138	9127	29531	18599	392.4
The city where participants spent their **last year**	137	12349	29531	19008	357.9

The external illuminance of 17650 lux in London, where the study was conducted, was also used as a baseline for grouping cities based on their external illuminances. In order to avoid repetitions, the cities where participants spent most of their lives and spent last year were named for ‘the city spent most of life’ and ‘the city spent last year’, respectively.

Method 1: Subjective ratings

Agreement between self-reported and measured daylight availability by people who have spent the majority of their lives and last year in cities with various external illuminances

Table 6. 13 depicts the distribution of people based on the agreement of perceived and measured illuminance levels, as well as the external illuminance of cities where participants spent most of their life and last year. In order to understand whether external illuminance of the cities spent most of life and last year on participants’ daylight perception, logistic regression was conducted. As summarized in **Table 6. 14**, there was no significant difference between the perception of daylight conditions in accordance with measurements and the mean of external illuminance of the cities where participants spent most of life and last year ($p=0.52$ and $p=0.42$, respectively).

Table 6. 13 *Comparison of differences in strongly agreeing, agreeing, and disagreeing with self-reported and measured daylight availability by the city where they spent their majority of lives and last year*

N=135		The geographic location of the residence	
		The mean of external illuminance where they spent **their majority of lives** (lux)	The mean of external illuminance where they spent **their last year** (lux)
Agreement	**Strongly agreement** in self-reporting and measurements	18418.6 (min: 9127- max: 27021)	19304.9 (min: 13300- max: 28700)
	Agreement in self-reporting and measurements	18773.9 (min: 9127- max: 29531)	18646.0 (min: 13300- max: 29531)
	Disagreement in self-reporting and measurements	18846.6 (min: 12258- max: 28987)	19338.8 (min: 12349- max: 28987)
	Total	18686.5 (min: 9127 -max: 29531)	19068.6 (min: 12349- max: 29531)

Table 6. 14 *Comparison of differences in agreeing and disagreeing with self-reported and measured daylight availability by the city where they spent their majority of lives and last year*

N=135		The geographic location of the residence	
		The mean of external illuminance where they spent **their majority of lives** (lux)	The mean of external illuminance where they spent **their last year** (lux)
Agreement	**Agreement** in self-reporting and measurements	18611.7 (min: 9127-max: 29531)	18909.6 (min: 13300- max: 29531)
	Disagreement in self-reporting and measurements	18846.6 (min: 12258- max: 28987)	19338.8 (min: 12349- max: 28987)
	Total	18686.5 (min: 9127-max: 29531)	19068.6 (min: 12349-max: 29531)

It was also important to explore if there is a tendency in the perception of people who disagree with daylight measurements from cities with different external illuminances. For this aim, logistic regression was carried out, and it was found that there is no trend in the perception of participants who perceive daylight conditions as slightly or significantly different from actual measurements and the external illuminance of the cities where they spent most of their life and last year ($p=0.33$ and 0.73, respectively).

Table 6. 15 *Tendency in daylight perception of people who disagree with actual measurements by the city where participants spent their majority of lives and last year*

N=184		The geographic location of the residence	
		Mean of external illuminance of the city where they spent **most of their life** (lux)	Mean of external illuminance of the city where they spent **their last year** (lux)
Perception accuracy	**Underperceived** of measured daylight availability	19728.8 (min: 12258- max:28987)	19612.9 (min: 12349- max: 28987)
	Overperceived of measured daylight availability	17621.2 (min: 12460 -max: 26309)	18927.6 (min: 13300- max: 26309)
	Total	18846.6 (min: 12258- max: 28987)	19338.8 (min: 12349- max: 28987)

Agreement between self-reported and measured daylight availability by people who have spent the majority of their lives and last year in cities with lower and higher external illuminance than London

In addition to using the cities' external illuminances directly, the external illuminance of 17650 lux in London, where the study was conducted, was used as a baseline for grouping cities based on their external illuminances, and the cities with lower and higher external illuminances were designated as UL and AL cities, respectively. **Table 6. 16** and **Table 6. 17** show the distribution of the agreement between self-reported and measured illuminance levels, as well as their relationship to the external illuminance of the cities where participants have spent the majority of their time. As can be seen, there is no discernible difference in the agreement of participants who spent the majority of their lives in cities with lower and higher external illuminance ($p=0.78$) because the proportions of people who agreed and disagreed with daylight measurements were at almost the same degree (30.4% and 33.3%). Although participants who spent their last year in a city with either lower or higher external illuminance than London did not have a significant impact on their agreement between self-reported and measured daylight availability ($p= 0.58$), it appears that the external illuminance of cities that spent the previous year has a greater influence on their agreement than cities that spent the majority of their lives (**Table 6. 18** and **Table 6. 19**).

Table 6. 16 *Comparison of differences in strongly agreeing, agreeing, and disagreeing with self-reported and measured daylight availability by people who spent the majority of their lives in cities with lower and higher external illuminance than London*

		The city where participants spent the **majority of their lives**		
N=135		**Cities with external illuminance lower than London** (<17650)	**Cities with external illuminance higher than London** (>17650)	**Total**
Agreement	**Strongly agreement** in self-reporting and measurements	24 (34.8%)	18 (27.3%)	42 (31.1%)
	Agreement in self-reporting and measurements	24 (34.8%)	26 (39.4%)	50 (37.0%)
	Disagreement in self-reporting and measurements	21 (30.4%)	22 (33.3%)	43 (31.9%)
	Total	69	66	135

Table 6. 17 *Comparison of differences in agreeing and disagreeing with self-reported and measured daylight availability by people who spent the majority of their lives in cities with lower and higher external illuminance than London*

		The city where participants spent the **majority of their lives**		
N=135		**Cities with external illuminance lower than London** (<17650)	**Cities with external illuminance higher than London** (>17650)	**Total**
Agreement	**Agreement** in self-reporting and measurements	48 (69.6%)	44 (66.7%)	92 (68.1%)
	Disagreement in self-reporting and measurements	21 (30.4%)	22 (33.3%)	43 (31.9%)
	Total	69	66	135

Table 6. 18 *Comparison of differences in strongly agreeing, agreeing and disagreeing with self-reported and measured daylight availability by people who spent their last years in cities with lower and higher external illuminance than London*

	N=135	The city where participants spent **their last years**		
		Cities with external illuminance lower than London (<17650)	**Cities with external illuminance higher than London** (>17650)	**Total**
Agreement	**Strongly agreement** in self-reporting and measurements	15 (24.2%)	19 (26.0%)	34 (25.2%)
	Agreement in self-reporting and measurements	27 (43.5%)	24 (32.9%)	51 (37.8%)
	Disagreement in self-reporting and measurements	20 (32.3%)	30 (41.1%)	50 (37.0%)
	Total	62	73	135

Table 6. 19 *Comparison of differences in agreeing and disagreeing with self-reported and measured daylight availability by people who spent their last years in cities with lower and higher external illuminance than London*

	N=135	The city where participants spent **their last years**		
		Cities with external illuminance lower than London (<17650)	**Cities with external illuminance higher than London** (>17650)	**Total**
Agreement	**Agreement** in self-reporting and measurements	42 (67.7%)	43 (58.9%)	85 (63.0%)
	Disagreement in self-reporting and measurements	20 (32.3%)	30 (41.1%)	50 (37.0%)
	Total	62	73	135

Table 6. 20 and **Table 6. 21** present the tendency of people who perceive daylight conditions differently from measurements depending on whether they have spent most of their life and last year in a city with lower or higher external illuminance than London. People who spent most of their lives in a city with lower external illuminance than London describe daylight conditions as higher than actual measurements (47.6%) than those who lived in a city with higher illuminance (36.4%). However, the proportion of the tendency in the agreement of participants who lived in a city with either lower or higher external illuminance in the last year is the same, indicating that the external illuminance of the city spent the previous year does not affect how they perceive daylight conditions.

Table 6. 20 *Tendency in daylight perception of people who disagree with actual measurements by the city where participants spent most of their life*

N=43		City where participants have spent **most of their lives**		
		Cities with external illuminance lower than London (<17650)	**Cities with external illuminance higher than London** (>17650)	**Total**
Perception accuracy	**Underperceived** of measured daylight availability	11 (52.4%)	14 (63.6%)	25 (58.1%)
	Overperceived of measured daylight availability	10 (47.6%)	8 (36.4%)	18 (41.9%)
	Total	21	22	43

__Table 6. 21__ Tendency in daylight perception of people who disagree with actual measurements by the city where participants spent their last year

N=50		The city where participants spent **their last years**		
		Cities with external illuminance lower than London (<17650)	**Cities with external illuminance higher than London** (>17650)	**Total**
Perception accuracy	**Underperceived** of measured daylight availability	12 (60%)	18 (60%)	30 (60%)
	Overperceived of measured daylight availability	8 (40%)	12 (40%)	20 (40%)
	Total	20	30	50

Additionally, a binary logistic regression was used to determine whether people from cities with lower or higher external illuminance than London tend to perceive daylight conditions lower or higher than actual measurements. As seen in **Table 6. 22** and **Table 6. 23**, there is no significant relationship between participants' daylight descriptions and the city where they spent most of their lives and the last year.

__Table 6. 22__ The likelihood of under- and overperceiving daylight conditions by the external illuminance of the city where participants spent most of their life

The external illuminance of the city where they spent the **majority of their lives** (lux)		**B**	**Standard Error (SE)**	**Significance (p)**	**Exp (B)**
Perception accuracy	**Underperceived** of measured daylight availability	-0.02	0.36	0.96	0.98
	Overperceived of measured daylight availability	0.38	0.37	0.30	1.46

Table 6. 23 *The likelihood of under- and overperceiving daylight conditions by the external illuminance of the city where participants spent their last year*

The external illuminance of the city where they spent **their last year** (lux)		**B**	**Standard Error (SE)**	**Significance (p)**	**Exp (B)**
Perception accuracy	**Underperceived** of measured daylight availability	-0.28	0.35	0.42	0.76
	Overperceived of measured daylight availability	0.22	0.37	0.54	1.25

Reference category: cities whose external illuminances are lower than London (<17650)

Agreement between self-reported and measured daylight availability by people who have spent the majority of their lives and last year in cities whose external illuminance grouped by quartiles method

No thresholds in the literature could be used to create a group of external illuminance of the cities from which individuals come from. The only way to group people was to use the external illuminance of London as a threshold and compare the perception of people from cities with either lower or higher external illuminance than London. Therefore, an additional grouping was done based on the quartiles method that splits the data into groups containing the same data points and measures the spread of values above and below the mean by dividing the distribution into four equal-sized groups. 25^{th}, 50^{th} and 75^{th} percentiles of the external illuminance data where participants spent most of their life were 15472, 17484 and 21840.5, respectively; therefore, the grouping below was done (**Table 6. 25**).

Table 6. 24 *Descriptive statistics of the groups created with* the quartiles method *on the median external diffuse horizontal illuminance of the cities where students spent time for majority of their lives and spent time in the last year*

Percentiles	**Group 1**	**Group 2**	**Group 3**	**Group 4**
The external illuminance of the city where participants spent the **majority of their lives**	Below 15472	Between 15472 and 17484	Between 17484 and 21840.5	Over 21840.5

Percentiles	**Group 1**	**Group 2**	**Group 3**	**Group 4**
The external illuminance of the city where participants spent **their last years**	Below 16008	Between 16008 and 17903	Between 17903 and 21840.5	Over 21840.5

Table 6. 25 and **Table 6. 26** present the distribution of participants' agreements on the self-reported and measured daylight availability and the external illuminance of cities they have spent most of their lives by groups created with the quartiles method. The below tables show a noticeable difference in the proportion of agreement between people who spent most of their lives in cities below 15472 lux (Group 1) and between 15472 and 17484 lux (Group 2). However, no trend was seen in the daylight perception of participants depending on the external illuminance where they spent most of life (p=0.46).

Table 6. 25 *Comparison of differences in strongly agreeing, agreeing, and disagreeing with self-reported and measured daylight availability by groups created with the quartiles method on the median external diffuse horizontal illuminance of the cities where students spent time for the majority of their lives*

N=135		The group of external illuminance of the cities where participants spent the **majority of their lives**			
		Group 1	**Group 2**	**Group 3**	**Group 4**
Agreement	**Strongly agreement** in self-reporting and measurements	8 (24.2%)	16 (45.7%)	6 (19.4%)	12 (33.3%)
	Agreement in self-reporting and measurements	13 (39.4%)	10 (28.6%)	14 (45.2%)	13 (36.1%)
	Disagreement in self-reporting and measurements	12 (36.4%)	9 (25.7%)	11 (35.5%)	11 (30.6%)
	Total	33	35	31	36

Table 6. 26 *Comparison of differences in agreeing and disagreeing with self-reported and measured daylight availability by groups created with the quartiles method on the median external diffuse horizontal illuminance of the cities where students spent time for the majority of their lives*

N=135		The group of external illuminance of the cities where participants spent the **majority of their lives**			
		Group 1	**Group 2**	**Group 3**	**Group 4**
Agreement	**Agreement** in self-reporting and measurements	21 (63.6%)	26 (74.3%)	20 (64.5%)	25 (69.4%)
	Disagreement in self-reporting and measurements	12 (36.4%)	9 (25.7%)	11 (35.5%)	11 (30.6%)
	Total	33	35	31	36

On the other hand, **Table 6. 27** and **Table 6. 28** show how different external illuminance of cities where participants spent their last year influences their agreement on the self-reported and measured illuminance levels. Similar to previous findings, it was found that the impact of the city where they have spent most of their life is not significantly important on daylight perception ($p=0.55$).

Table 6. 27 *Comparison of differences in strongly agreeing, agreeing and disagreeing with self-reported and measured daylight availability by groups created with the quartiles method on the median external diffuse horizontal illuminance of the cities where students spent their last year*

N=135		The group of external illuminance of the cities where participants spent **their last years**			
		Group 1	**Group 2**	**Group 3**	**Group 4**
Agreement	**Strongly agreement** in self-reporting and measurements	6 (16.7%)	9 (29.0%)	9 (26.5%)	10 (29.4%)
	Agreement in self-reporting and measurements	18 (50.0%)	12 (38.7%)	9 (26.5%)	12 (35.3%)
	Disagreement in self-reporting and measurements	12 (33.3%)	10 (32.3%)	16 (47.1%)	12 (35.3%)
	Total	36	31	34	34

Table 6. 28 *Comparison of differences in agreeing and disagreeing with self-reported and measured daylight availability by groups created with the quartiles method on the median external diffuse horizontal illuminance of the cities where students spent their last year*

N=135		The group of external illuminance of the cities where participants spent **their last years**			
		Group 1	**Group 2**	**Group 3**	**Group 4**
Agreement	**Agreement** in self-reporting and measurements	24 (66.7%)	21 (67.7%)	18 (52.9%)	22 (64.7%)
	Disagreement in self-reporting and measurements	12 (33.3%)	10 (32.3%)	16 (47.1%)	12 (35.3%)
	Total	36	31	34	34

A binary logistic regression was used to determine whether the external illuminance of the cities where participants spent most of their life or last year affected the perception of people who perceive daylight conditions very differently. As seen in **Table 6. 29**, more than half of the participants (58.3%) in Group 1 perceived daylight conditions as higher than measured. However, there is no trend in the proportion of people who under or overperceived the daylight conditions depending on the external illuminance of cities where they spent most of their life (p=0.26). On the other, **Table 6. 30** also showed that the majority of people (80%) underperceived the conditions in Group 2 but similar to the previous one, there is no pattern in the likelihood of perceiving under- or over-perception of daylight conditions with the increase of external illuminance of the city where they spent their last year (p=0.32).

Table 6. 29 *Tendency in daylight perception of people who disagree with actual measurements by the city where participants spent most of their lives by groups created with quartiles method*

N=43		The group of external illuminance of the cities where participants spent the **majority of their lives**			
		Group 1	**Group 2**	**Group 3**	**Group 4**
Perception accuracy	**Underperceived** of measured daylight availability	5 (41.7%)	6 (66.7%)	6 (54.5%)	8 (72.7%)
	Overperceived of measured daylight availability	7 (58.3%)	3 (33.3%)	5 (45.5%)	3 (27.3%)
	Total	12	9	11	11

Table 6. 30 *Tendency in daylight perception of people who disagree with actual measurements by the city where participants spent the last year by groups created with quartiles method*

N=50		The group of external illuminance of the cities where participants spent **their last year**			
		Group 1	**Group 2**	**Group 3**	**Group 4**
Perception accuracy	**Underperceived** of measured daylight availability	6 (50%)	8 (80%)	7 (43.8%)	9 (75%)
	Overperceived of measured daylight availability	6 (50%)	2 (20%)	9 (56.3%)	3 (25%)
	Total	12	10	16	12

Agreement between self-reported and measured daylight availability by people who have spent the majority of their lives and last year in cities at different latitudes

As known, the amount of external lighting levels decreases as latitude increases. Therefore, the latitude of the city where participants lived most of their life and last year (See **Appendix 6**) could be another important element that needs to be considered while assessing their daylight perception. In parallel with the previous findings, there was no significant relationship between the city's latitude and participants' daylight perception ($p=0.13$, $p=0.14$). However, people from cities with higher latitudes, ultimately cities with less daylight availability, appear to overperceive the daylight conditions in the UK, which needs further investigation.

Table 6. 31 *Tendency in daylight perception of people who disagree with actual measurements by latitude*

N=135		The geographic location of the residence	
		The mean latitude where they spent **their majority of lives** (lux)	The mean latitude where they spent **their last year** (lux)
Perception accuracy	**Underperceived** of measured daylight availability	26.4 (min:-37.0 -max: 53.3)	32.6 (min:-32.8 - max:59.3)
	Overperceived of measured daylight availability	39.7 (min:10.5- max: 53.3)	34.21 (min:-43.5- max:53.3)
	Total	31.98 (min:-37.0-max:53.3)	33.23 (min:-43.5 -max:59.3)

Method 2: Seat preference

The horizontal illuminances of the desks chosen by people who preferred their seats were analysed to investigate if there is a link between the city's external illuminance where participants spent most of their life and the last year and their daylight perception. For this aim, a linear regression was performed between the horizontal illuminance on the chosen desk and the cities' external illuminances where students came from. As seen in **Figure 6. 10** and **Figure 6. 11**, any difference between daylight availability on the selected desk and the external illuminances of the cities where participants spent most of their life and last year was not found ($p=0.51$ and $p=0.53$, respectively).

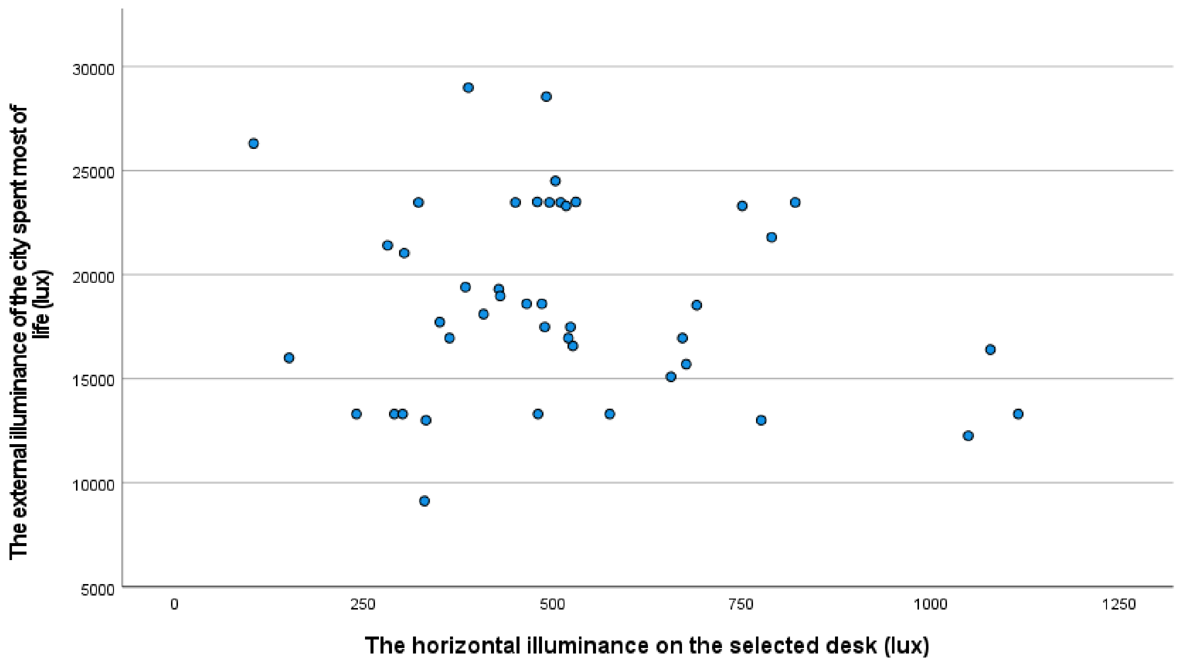


Figure 6. 10 *Relationship between the illuminance level of the selected desks chosen by participants who reported being satisfied with their seats, and the external illuminance of the city where participants spent the majority of their lives*

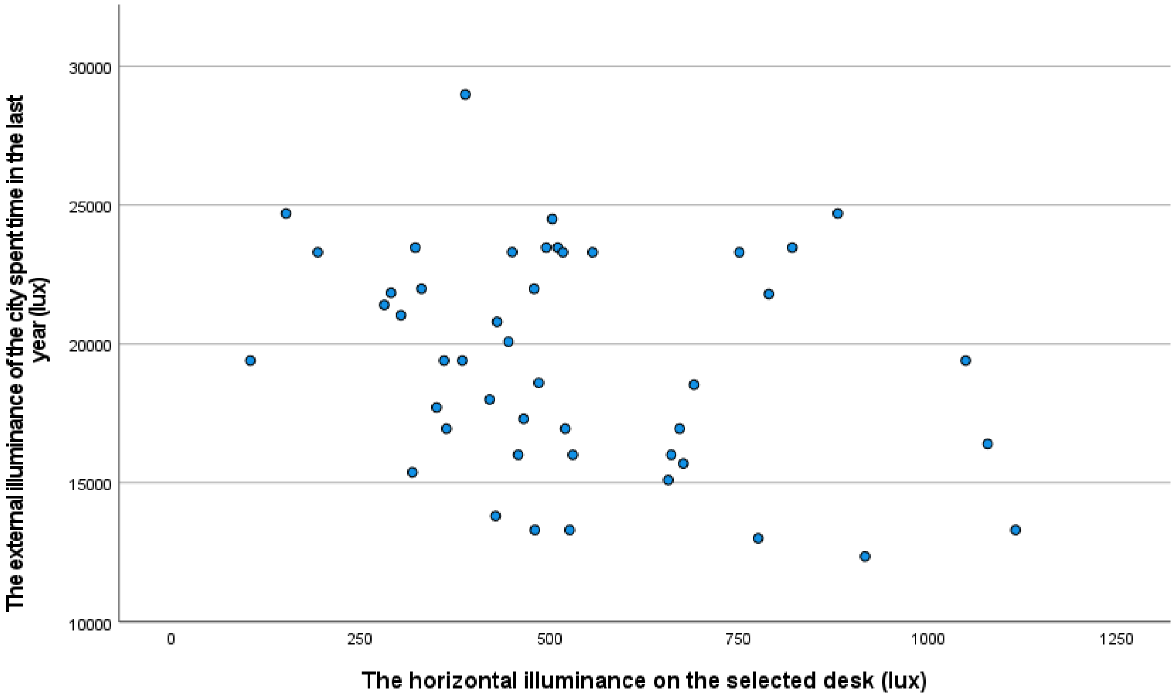


Figure 6. 11 *Relationship between the illuminance level of the selected desks chosen by participants who reported being satisfied with their seats, and the external illuminance of the city where participants spent their last year*

Lastly, an ordinal regression was conducted to investigate whether participants' agreement between self-reported and measured illuminances is influenced by the external illuminance of the cities where participants spent most of their lives and last year. As seen in **Table 6. 32** and **Table 6. 33**, there is no difference between people who spent most of their life and last year in a city whose external illuminance is higher or lower than London in terms of perceived amount of daylight (p= 0.49 and 0.51). Although there is no statistically significant difference, it is clear that the impact of the external illuminance of the city where participants spent the majority of their lives on daylight perception is more influential than the city where they spent the last year.

Table 6. 32 *Agreement between self-reported and measured illuminance levels on desks by the external illuminance of the city where participants spent the majority of their lives*

Cities where participants have spent **most of their lives**		Mean of horizontal illuminance on the desk (lux)			
		Cities with external illuminance lower than London (<17650)	**Cities with external illuminance lower than London** (>17650)	**Total**	**p-value**
Self-reporting of participants	**Very low**	570.7	349.7	423.3	0.210
	Low	438.3	530.0	481.5	0.270
	Below average	477.9	635.4	540.9	0.373
	Above average	567.2	561.9	564.5	0.740
	High	685.8	578.2	632.0	0.675
	Very high	448.5	777.0	612.7	0.346
	Total	539.3	560.9	549.8	0.343

Table 6. 33 *Agreement between self-reported and measured illuminance levels on desks by the external illuminance of the city where participants spent their last years*

Cities where participants have spent **their last year**		The mean of horizontal illuminance on the desk (lux)			
		Cities with external illuminance lower than London (<17650)	**Cities with external illuminance lower than London** (>17650)	**Total**	**p-value**
Self-reporting of participants	**Very low**	468.0	365.3	406.4	0.348
	Low	565.1	551.8	557.7	0.858
	Below average	608.1	557.1	578.7	0.795
	Above average	542.8	543.9	543.3	0.735
	High	628.7	605.0	615.6	0.654
	Very high	825.0	384.0	678.0	0.213
	Total	575.8	539.9	556.4	0.513

6.3.4. Previous luminous environment

Method 1: Subjective ratings

Prior studies have shown that the amount of daylight exposure while outdoors or seated near a window indoors is important because it affects how much melatonin suppresses our response to daylight and, ultimately, how we perceive and assess lighting conditions. In addition to the participants' acclimation to the outdoor lighting circumstances described in the preceding section, it is also critical to take into account the lighting conditions that a subject recently experienced. Therefore, participants in this study were asked about their exposure to outdoor daylight conditions on average over the previous four weeks (Question 9 in **Appendix 5**). The amount of daylight participants were exposed to was calculated based on the developed method described in Chapter 6, **section 6.2.7.2.** using participants' daylight exposure statements, data from daylight simulations and London's hourly median external illumination over the last four weeks.

Table 6. 34 shows the range of daily average daylight exposure reported by participants over the previous four weeks. In this study, the average amount of daylight exposure was 18308.6 lux-hours. Over the last four weeks, one hundred sixty-eight subjects were exposed to daylight conditions in London for a minimum of 1161.1 lux hours and a maximum of 87169.9 lux hours. The minimum light exposure was reported by a student who has six regular days per week, spending time outdoors from 8:00 to 8:15 on workdays and 8:00 to 8:30 on free days. On the other hand, the maximum light exposure belongs to a student who has a regular day per week and spends time outside from 8:00 to 10:00 and 14:00-15:30 on workdays and 8:00 to 14:00 on free days.

Table 6. 34 *Descriptive statistics on the average daylight exposure of participants in London over the previous four weeks*

	Number of cases	**Minimum** (lux-hour)	**Maximum** (lux-hour)	**Mean** (lux-hour)	**Std deviation** (lux-hour)
Average daylight exposure of participants in London over the previous four weeks	168	1161.1	87169.9	18308.6	11444.9

Agreement between self-reported and measured daylight availability by the average daylight exposure of participants over the previous four weeks

Logistic regression was used to determine whether participants perceived daylight conditions as measured depending on how much daylight they had been exposed to during the previous four weeks. No statistically significant difference was found between participants who perceive daylight conditions based on measurements and those who do not depend on prior daylight exposure (p=0.26). As seen in **Table 6. 36**, the difference in the amount of daylight that participants were exposed to between those perceived daylight conditions that are consistent and those that are inconsistent is minimal. However, **Table 6. 35** shows that participants whose daylight perception closely matches actual measurements are more likely to live in cities with lower external illuminances than others.

Table 6. 35 *Comparison of differences in strongly agreeing, agreeing, and disagreeing with self-reported and measured daylight availability by the average daylight exposure of participants in London over the previous four weeks*

		The mean **average daylight exposure of the participants** over the last four weeks (lux-hour)
Agreement	**Strongly agreement** in self-reporting and measurements	17115.7 (min: 1551.6 – max: 44190.3)
	Agreement in self-reporting and measurements	19479.3 (min: 3104.1– max: 45159.7)
	Disagreement in self-reporting and measurements	18941.1 (min: 1161.1– max: 87169.9)
	Total	18568.1 (min: 1161.1– max: 87169.9)

Table 6. 36 *Comparison of differences in agreeing and disagreeing with self-reported and measured daylight availability by the average daylight exposure of participants in London over the previous four weeks*

		The mean **average daylight exposure of the participants** over the last four weeks (lux-hour)
Agreement	**Agreement** in self-reporting and measurements	18393.3 (min: 1551.6 – max: 45159.7)
	Disagreement in self-reporting and measurements	18941.100 (min: 1161.1– max: 87169.9)
	Total	18568.1 (min: 1161.1– max: 87169.9)

As seen in **Table 6. 37**, people who perceive daylight conditions that differ slightly or significantly from actual measurements are more likely to underperceive daylight conditions when living in a city with lower external illuminance. However, logistic regression did not statistically demonstrate a significant relationship (p=0.77).

Table 6. 37 *Tendency in daylight perception of people who disagree with actual measurements by the average daylight exposure of participants in London over the previous four weeks*

N=184		The mean of **the average daylight exposure of participants** in London over the previous four weeks (lux-hour)
Perception accuracy	**Underperceived** of measured daylight availability	18449.5 (min: 1161.1 - max: 38563.3)
	Overperceived of measured daylight availability	19560.9 (min: 3701.7-max: 87169.9)
	Total	18941.1 (min: 1161.1 - max: 87169.9)

Agreement between self-reported and measured daylight availability by the average daylight exposure of participants over the previous four weeks grouped by quartiles method

There were no thresholds in the literature that could be used to group the amount of daylight that participants were exposed to. Individuals' exposure to daylight was thus grouped using the quartiles technique by measuring the spread of values above and below the mean and dividing the distribution into four groups. 25^{th}, 50^{th} and 75^{th} percentiles of the daylight exposure data were 10231.3, 15848.1 and 23817.4, respectively, and thus, the below grouping was performed (**Table 6. 38**).

Table 6. 38 *Descriptive statistics of the groups created with the quartiles method on the average daylight exposure of participants in London over the previous four weeks*

Percentiles	**Group 1**	**Group 2**	**Group 3**	**Group 4**
Average daylight exposure of participants in London over the previous four weeks (lux-hour)	Below 10231.3	Between 10231.3 and 15848.1	Between 15848.1 and 23817.4	Over 23817.4

It was also investigated whether the participants' level of daylight exposure in the previous four weeks influenced how they responded to daylight conditions in accordance with measurements (**Table 6. 39** and **Table 6. 40**). As can be seen, the proportion of participants who perceived daylight conditions in consistent and inconsistent with actual daylight conditions is fairly the same in each group. It was shown that the amount of daylight exposure does not affect the likelihood of perceiving in accordance with the measurements. ($p=0.35$).

Table 6. 39 *Comparison of differences in strongly agreeing, agreeing, and disagreeing with self-reported and measured daylight availability by groups created with the quartiles method on the average daylight exposure of participants in London over the previous four weeks*

N=163		The group of average daylight exposure of participants in London over the previous four weeks			
		Group 1	**Group 2**	**Group 3**	**Group 4**
Agreement	**Strongly agreement** in self-reporting and measurements	12 (30.8%)	17 (42.5%)	11 (26.2%)	11 (26.2%)
	Agreement in self-reporting and measurements	14 (35.9%)	10 (25.0%)	18 (42.9%)	18 (42.9%)
	Disagreement in self-reporting and measurements	13 (33.3%)	13 (32.5%)	13 (31.0%)	13 (31.0%)
	Total	39	40	42	42

Table 6. 40 *Comparison of differences in agreeing and disagreeing with self-reported and measured daylight availability by groups created with the quartiles method on the average daylight exposure of participants in London over the previous four weeks*

N=163		The group of average daylight exposure of participants in London over the previous four weeks			
		Group 1	**Group 2**	**Group 3**	**Group 4**
Agreement	**Agreement** in self-reporting and measurements	26 (66.7%)	27 (67.5%)	29 (69.0%)	29 (69.0%)
	Disagreement in self-reporting and measurements	13 (33.3%)	13 (32.5%)	13 (31.0%)	13 (31.0%)
	Total	39	40	42	42

The impact of the previous four weeks of daylight exposure in London on participants' daylight perception may also play a role in their disagreement on the perception of daylight conditions that differ greatly from measurements. As seen in **Table 6. 41**, no discernible trend indicates a change in people's perceptions of daylight due to their exposure to daylight (p=0.11). It is obvious, however, that people exposed to outdoor daylight conditions ranging from 15848.1 to 23817.4 lux-hours (Group 3) are very likely to perceive daylight conditions lower than actual measurements.

Table 6. 41 *Tendency in daylight perception of people who disagree with actual measurements by the average daylight exposure of participants in London over the previous four weeks*

N=52		The group of average daylight exposure of participants in London over the previous four weeks			
		Group 1	**Group 2**	**Group 3**	**Group 4**
Perception accuracy	**Underperceived** of measured daylight availability	6 (46.2%)	6 (46.2%)	10 (76.9%)	7 (53.8%)
	Overperceived of measured daylight availability	7 (53.8%)	7 (53.8%)	3 (23.1%)	6 (46.2%)
	Total	13	13	13	13

Furthermore, another logistic regression was carried out to investigate whether the likelihood of underperceiving and overperceiving daylight conditions varies depending on how much daylight participants were exposed to during the previous four weeks. **Table 6. 42** shows a perception pattern similar to that seen in people who disagree with daylight measurements, and daylight exposure of participants greatly affects their likelihood of perceiving conditions lower than actual measurements (p=0.04). It could be interpreted that increased daylight exposure leads to higher daylight expectations and lower satisfaction when compared to those exposed to less daylight. However, there was no relationship between participants' overperception and their exposure to daylight (p=0.48) (**Table 6. 43**).

Table 6. 42 *The likelihood of underperceiving daylight conditions by the average daylight exposure of participants in London over the previous four weeks*

	Underprediction of objectively measured daylight availability	**B**	**Standard Error (SE)**	**Significance (p)**	**Exp (B)**
Daylight exposure	Group 1	-	-	0.054	-
	Group 2	-0.46	0.51	0.372	0.63
	Group 3	0.81	0.46	0.081	2.25
	Group 4	0.42	0.47	0.364	1.53

Reference category: Group 1

Table 6. 43 *The likelihood of overperceiving daylight conditions by the average daylight exposure of participants in London over the previous four weeks*

	Overprediction of objectively measured daylight availability	**B**	**Standard Error (SE)**	**Significance (p)**	**Exp (B)**
Daylight exposure	Group 1	-	-	0.506	-
	Group 2	0.22	0.46	0.631	1.25
	Group 3	0.14	0.46	0.756	1.15
	Group 4	-0.47	0.49	0.336	0.62

Reference category: Group 1

Method 2: Seat preference

Participants in this study who reported being satisfied with their seats were considered to have chosen those desks due to daylight availability. Thus, the horizontal illuminances on the selected desks by people who preferred the seats were analysed to investigate the impact of four weeks of exposure to outdoor daylight conditions in London on their daylight perception. Linear regression was carried out and presented in **Figure 6. 12**. As can be seen, no significant relationship between participants' daylight exposure and their daylight perceptions was investigated (p=0.55).

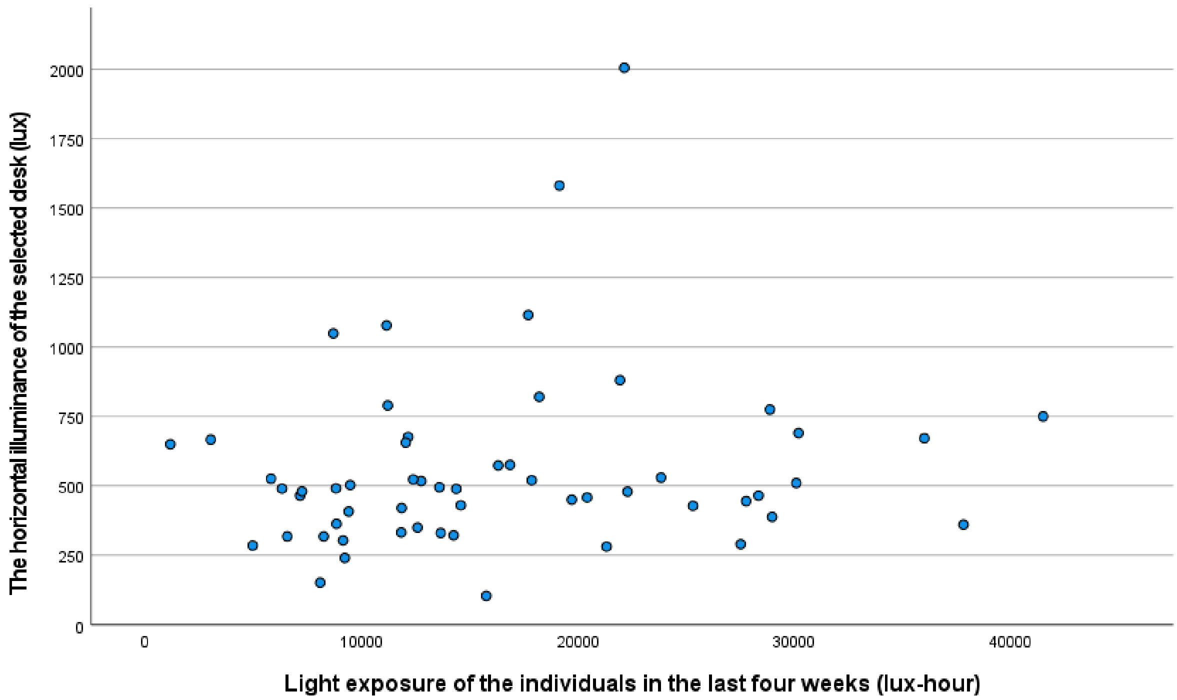


Figure 6. 12 *The relationship between the illuminance level of the selected desks chosen by participants who reported being satisfied with their seats, and the average daylight exposure of participants in London over the previous four weeks*

Last but not least, an ordinal regression test was performed to determine whether the self-reporting of participants and the amount of daylight exposure they experienced during the previous four weeks are related (**Table 6. 44**). The findings showed no difference in daylight perception of people between those who had been exposed to different amounts of daylight prior to the study (p=0.24).

Table 6. 44 *Agreement between self-reported and measured illuminance levels on desks by the average daylight exposure of participants in London over the previous four weeks*

The average daylight exposure of participants in London over the previous four weeks		The mean of horizontal illuminance on the desk (lux)					
		Group 1	**Group 2**	**Group 3**	**Group 4**	**Total**	**p-value**
Self-reportings	**Very low**	506.5	227.0	-	581.5	438.3	0.712
	Low	455.5	789.0	-	498.7	532.7	0.607
	Below average	-	449.2	1111.7	537.0	689.6	0.249
	Above average	441.8	554.0	672.4	489.6	531.5	0.866
	High	-	548.0	841.3	577.7	669.1	0.453
	Very high	480.0	-	-	-	480.0	0.998
	Total	453.3	500.9	802.7	527.6	562.4	-

6.3.5. Sociocultural background

As highlighted in the previous chapter, the variation in the evaluation of the lighting levels could depend on sociocultural context and, ultimately, values, customs, and traditions rather than acclimatisation to some kinds of lighting conditions. Individuals with the same sociocultural background might judge the conditions similarly or have identical behaviour patterns. Hence, they may have common attitudes and perceptions towards daylight conditions. From another point of view, individual lifestyle and daily routines could be related to sociocultural background, and therefore behavioural factors that are not mostly accounted for in most studies could affect the perception of lighting quality.

In sum, sociocultural background, lifestyle and related perceptual and behavioural patterns could cause inter-individual differences in daylight perception. However, it was not possible to assess the inter-individual differences in daylight perception using a questionnaire; because this required detailed information from participants using different techniques such as interviews. Therefore, the influence of participants' sociocultural background on their daylight perception is beyond the scope of this study. It is highly recommended to conduct in-depth interviews with participants to define the perceptual patterns of people from a similar sociocultural context for future research.

6.3.6. Other factors

The previous sections sought to determine whether the components listed in the systematic review as part of the cultural background in the lighting environment affect how daylight was perceived. Additionally, participants' definitions of cultural background, the length of time spent in London, and demographic factors like age and gender may all impact how they perceive the quality of daylight.

6.3.7.1. Definition of cultural background

Cultural background is a broad term with various definitions in various fields. Therefore, it is unclear how people define their cultural background and what consequences may result from their cultural background description. In order to better understand the definition of cultural background from the participants' perspective, they were asked in an open-ended question how they would describe their cultural background (**Figure 6. 13**).

5. How do you describe your cultural background? ________________________
(it depends on your own definition of culture as a part of your life style)

Figure 6. 13 *The question related to the definition of cultural background*

Participants' responses showed that cultural background could be defined in various ways, as shown in **Table 6. 45.** Nationality is the most commonly used definition, followed by a few adjectives and the places where people feel they belong. Surprisingly, few individuals described their cultural background in unusual ways, such as religious, philosophical, or political perspectives.

Table 6. 45 *Cultural background definitions provided by participants*

Cultural background definition	Number of people
Nationality, e.g., Greek, Chinese, British, Latin-American, etc.	70 (31.5%)
Adjective, e.g., kind, hospitable, extraordinary, colourful, diverse, international, visitor of different origins, self-independent & long-historic, rich, warm-blooded, minimalist, very mixed within Europe, open to other cultures, humanitarian, benevolence, family-oriented, northern, etc.	35 (15.8%)
Region, e.g., Mediterranean, European, Eastern Asian, Western, etc	14 (6.3%)
Cultural structure, e.g., Traditional Chinese culture, Islamic Traditional culture, Modern Chinese culture, Cantonese culture, etc.	14 (6.3%)
Ethnicity, e.g., White British, Asian, Mixed, Gypsy, etc.	11(5.0%)
The place born and raised up, e.g. (1) born and bred in Singapore which is a multicultural environment, but mainly grew up around Chinese due to school and residential environment, (2) Mixed, primarily English but Mauritian: Indian origin,(3) Londoner + Ghanaian, (4) HAN nationality, Chinese mainlander, Chinese, etc.	8 (3.6%)
Political approach, e.g., conservative, left-winger, etc.	3 (1.4%)
Education level, e.g., postgraduate, Bachelor of arts, undergraduate, etc.	3 (1.4%)
Philosophical approach, e.g., Confucianism, pragmatism, etc.	2 (0.9%)
Economic situation, e.g., Dutch middle-class	1 (0.5%)
	167

The individuals' definition of the cultural background represents norms and values that subjects belong to. The norms and values that shape an individual's lifestyle may influence their perspectives, such as the importance of daylight in life, as well as their behaviours, such as the amount of time they are exposed to daylight. As a result, the perception of daylight may be linked to how people define culture. **Table 6. 46** shows that the logistic regression revealed no significant relationship between individuals' definitions of cultural background and their perceptions of daylight (p=0.33).

Table 6. 46 *Agreement in self-reported and measured daylight availability by the cultural background definition of participants*

Cultural background definition of participants	**Agreement** in self-reporting and measurements	**Disagreement** in self-reporting and measurements
Nationality	20 (37.0%)	39 (29.8%)
Adjective	9 (16.7%)	17 (13.0%)
Region	2 (3.7%)	10 (7.6%)
Cultural structure	1 (1.9%)	11 (8.4%)
Ethnicity	3 (5.6%)	6 (4.6%)
The place born and raised up	1 (1.9%)	7 (5.3%)
Political approach	0 (0.0%)	3 (2.3%)
Education level	0 (0.0%)	2 (1.6%)
Philosophical approach	0 (0.0%)	1 (0.8%)
Economic situation	1 (1.9%)	0 (0%)

6.3.7.2. Length of time spent in London

Method 1: Subjective ratings

Previous research has shown that subjective lighting assessment of the same environment is not always consistent, possibly due to individuals' acclimatisation to specific outdoor daylight conditions. As mentioned in Chapter 5, Residents in Tel Aviv, for example, where illuminance levels are above 75,000-lux for approximately 66% of the time, may not have the same daylight expectation as residents in Berlin, where similar illuminance levels are rare. However, in addition to external illuminance levels, the length of time spent in that city also matters. In this context, people who have spent long periods in London are anticipated to become more accustomed to the city's daylight conditions than those who have spent less time there. As a result, those individuals are expected to perceive daylight conditions more consistent with measurements.

Table 6. 47 and **Table 6. 48** show the percentage of people who perceive daylight conditions that are consistent or inconsistent with those measured. When comparing time durations of less than 12 months and between 12 and 36 months, it appears that the proportion of people who perceive daylight conditions far from actual measurements decreases with time, from 36.8% to 28.3%. It was an expected finding, given that people are accustomed to changing daylight conditions over time. Surprisingly, after 36 months, that proportion has nearly returned to where it started (33.3%). A binary logistic test revealed that the amount of time spent in London did not affect how participants perceived daylight conditions ($p=0.61$).

Table 6. 47 *Comparison of differences in strongly agreeing, agreeing, and disagreeing with self-reported and measured daylight availability by the length of time spent in London*

N=184		The length of time spent by participants in London		
		Below 12 months	**12-36 months**	**Over 36 months**
Agreement	**Strongly agreement** in self-reporting and measurements	24 (27.6%)	16 (34.8%)	14 (27.5%)
	Agreement in self-reporting and measurements	31 (35.6%)	17 (37.0%)	20 (39.2%)
	Disagreement in self-reporting and measurements	32 (36.8%)	13 (28.3%)	17 (33.3%)
	Total	87	46	51

Table 6. 48 *Comparison of differences in agreeing and disagreeing with self-reported and measured daylight availability by the length of time spent in London*

N=184		The length of time spent by participants in London		
		Below 12 months	**12-36 months**	**Over 36 months**
Agreement	**Agreement** in self-reporting and measurements	55 (63.2%)	33 (71.7%)	34 (66.7%)
	Disagreement in self-reporting and measurements	32 (36.8%)	13 (28.3%)	17 (33.3%)
	Total	87	46	51

Table 6. 49 presents the tendency of people who describe daylight conditions as slightly or significantly different from actual measurements. It was found that people who spent less than a year in London are twice as likely to perceive daylight conditions as being lower than actual measurements compared to those who spent between 12 and 36 months (p=0.05). However, there is no trend in people's perceptions of daylight based on time spent in London over time (p=0.14).

Table 6. 49 *Tendency in daylight perception of people who disagree with actual measurements by the length of time spent in London*

N=62		The length of time spent by participants in London		
		Below 12 months	**12-36 months**	**Over 12 months**
Perception accuracy	**Underperceived** of measured daylight availability	23 (44.8%)	4 (27.7%)	10 (35.3%)
	Overperceived of measured daylight availability	9 (27.6%)	9 (38.3%)	7 (37.3%)
	Total	32	13	17

Method 2: Seat preference

Linear regression between the length of time spent in London and daylight availability of the chosen desk by people who are satisfied with their seats to investigate whether daylight perception of participants changes over time. As seen in **Figure 6. 14**, the length of stay in London does not influence their seat selections (p=0.65).

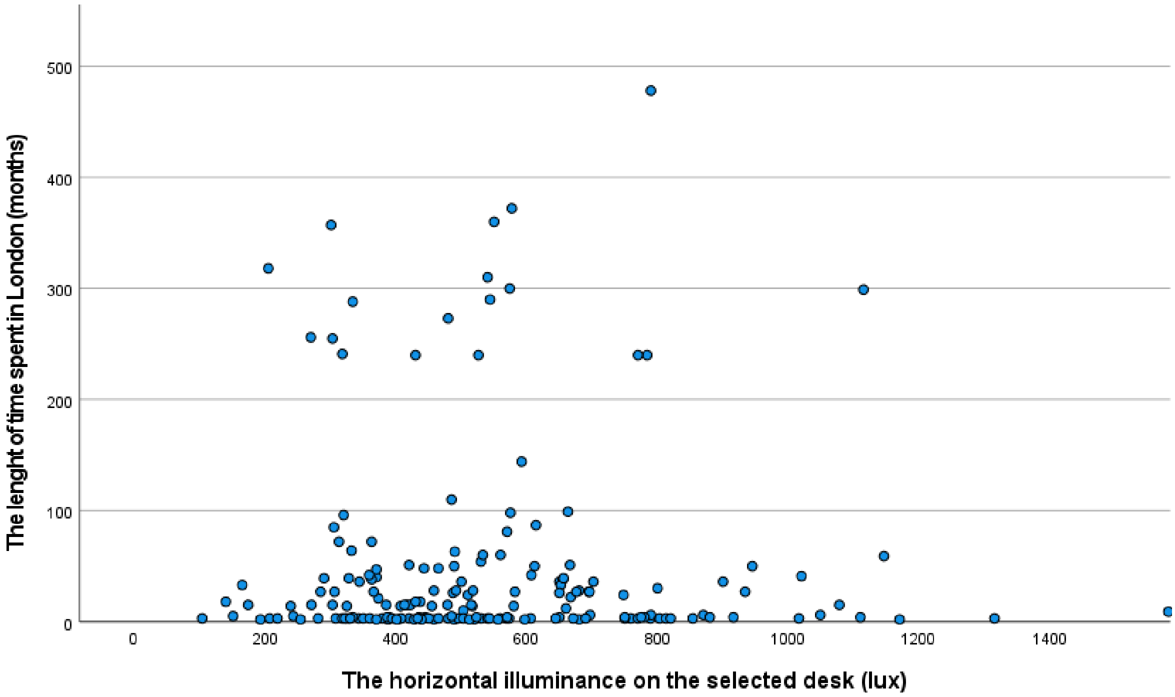


***Figure 6. 14** The relationship between the illuminance level of the selected desks chosen by participants who reported being satisfied with their seats, and the length of time spent by participants in London*

6.3.7.3. Gender

Method 1: Subjective ratings

Differences in people's perceptions of daylight may also be influenced by gender. **Table 6. 50** and **Table 6. 51** present the agreement between self-reported and measured daylight availability by different genders. As seen, females are slightly more likely to perceive daylight conditions differently than actual measurements than men. However, no significant relationship was found among daylight perception of people from different genders (p=0.28)

Table 6. 50 *Comparison of differences in strongly agreeing, agreeing, and disagreeing with self-reported and measured daylight availability by gender*

N=185		Gender		
		Male	**Female**	**Prefer not to say**
Agreement	**Strongly agreement** in self-reporting and measurements	25 (32.5%)	29 (27.4%)	0 (0%)
	Agreement in self-reporting and measurements	29 (37.7%)	38 (35.8%)	1 (50%)
	Disagreement in self-reporting and measurements	23 (29.9%)	39 (36.8%)	1 (50%)
	Total	77	106	2

Table 6. 51 *Comparison of differences in agreeing and disagreeing with self-reported and measured daylight availability by gender*

N=185		Gender		
		Male	**Female**	**Prefer not to say**
Agreement	**Agreement** in self-reporting and measurements	54 (70.1%)	67 (63.2%)	1 (50%)
	Disagreement in self-reporting and measurements	23 (29.9%)	39 (36.8%)	1 (50%)
	Total	77	106	2

Table 6. 52 shows the gender difference in daylight perception of people who disagree with actual measurements. Their likelihood of under or overperceiving daylight conditions seems fairly similar, and there is no statistical difference in how gender perceived daylight conditions (p=0.35). However, after evaluating all participants, it was found that females were much more likely (1.7 times) than males to overperceive the amount of daylight (p=0.08).

Table 6. 52 *Tendency in daylight perception of people who disagree with actual measurements by gender*

N=63		Gender		
		Male	**Female**	**Not stated**
Perception accuracy	**Underperceived** of measured daylight availability	13 (56.5%)	23 (59%)	1 (100%)
	Overperceived of measured daylight availability	10 (43.5%)	16 (41%)	0 (0%)
	Total	23	39	1

Method 2: Seat preference

The horizontal illuminance on the selected desks by participants who consciously preferred the library desks was examined across genders. **Table 6. 53** demonstrates the distribution of people from various ethnic backgrounds and their perceptions of daylight. As can be seen, the difference between genders' illuminance levels on the desks is negligible, indicating that gender does not influence participants' perception of daylight (p=0.43).

Table 6. 53 *The mean of daylight availability on desks chosen by participants from various genders who reported being satisfied with their seats*

Gender	**Mean of daylight availability at the seat**	**Std deviation**
Males	546.4	271.7
Females	546.3	267.3
Prefer not to say	708.0	294.1

6.3.7.4. Age

Method 1: Subjective ratings

Age, as one of the demographic variables, may influence participants' perceptions of daylight. As seen in **Table 6. 54** and **Table 6. 55**, most participants in this study are between 20 and 30. Logistic regression was used to determine whether daylight perception varies with age. It was found that age does not explain the variation in the perception of daylight conditions consistent or inconsistent with the measurements (p=0.73). The ages of those who disagreed with the actual measurements also did not affect their likelihood of under or overperceiving daylight conditions (p=0.21) (**Table 6. 56**)

Table 6. 54 *Comparison of differences in strongly agreeing, agreeing, and disagreeing with self-reported and measured daylight availability by age*

<table>
<tr><th colspan="2" rowspan="2">N=175</th><th colspan="5">Age groups of participants</th></tr>
<tr><th>Under 20</th><th>20-24</th><th>25-29</th><th>30-34</th><th>Over 35</th></tr>
<tr><td rowspan="4">Agreement</td><td>Strongly agreement in self-reporting and measurements</td><td>3 (37.5%)</td><td>27 (31.4%)</td><td>11 (22.0%)</td><td>6 (33.3%)</td><td>4 (30.8%)</td></tr>
<tr><td>Agreement in self-reporting and measurements</td><td>1 (12.5%)</td><td>30 (34.9%)</td><td>23 (46.0%)</td><td>4 (22.2%)</td><td>5 (38.5%)</td></tr>
<tr><td>Disagreement in self-reporting and measurements</td><td>4 (50.0%)</td><td>29 (33.7%)</td><td>16 (32.0%)</td><td>8 (44.4%)</td><td>4 (30.8%)</td></tr>
<tr><td>Total</td><td>8</td><td>86</td><td>50</td><td>18</td><td>13</td></tr>
</table>

Table 6. 55 *Comparison of differences in agreeing and disagreeing with self-reported and measured daylight availability by age*

N=175		Age groups of participants				
		Under 20	**20-24**	**25-29**	**30-34**	**Over 35**
Agreement	**Agreement** in self-reporting and measurements	4 (50%)	57 (66.3%)	34 (68%)	10 (55.6%)	9 (69.2%)
	Disagreement in self-reporting and measurements	4 (50%)	29 (33.7%)	16 (32%)	8 (44.4%)	4 (30.8%)
	Total	8	86	50	18	13

Table 6. 56 *Tendency in daylight perception of people who disagree with actual measurements by age*

N=61		Age groups of participants				
		Under 20	**20-24**	**25-29**	**30-34**	**Over 35**
Perception accuracy	**Underperceived** of measured daylight availability	3 (75%)	15 (51.7%)	12 (75%)	4 (50%)	3 (75%)
	Overperceived of measured daylight availability	1 (25%)	14 (48.3%)	4 (25%)	4 (50%)	1 (25%)
	Total	4	29	16	8	4

Method 2: Seat preference

The horizontal illuminances of the desks chosen by participants who stated that they preferred the desks were assessed based on the participants' ages to investigate if age influences how they perceive daylight conditions. As shown in **Table 6. 57**, there is no age-related trend in the mean of daylight availability on the selected desks, implying that participants' age does not influence their seat selection or daylight preference (p=0.72).

Table 6. 57 *The mean of daylight availability on desks chosen by participants from various age groups who reported being satisfied with their seats*

Age groups	**Mean of daylight availability at the seat**	**Std deviation**
Under 20	462.5	168.4
20-24	562.3	269.6
25-29	565.6	332.1
30-34	474.7	197.1
Over 35	574.6	193.9

6.3.7. Limitations and future work

- The sample size of this study could be a limitation since it did not allow the generalisation of the findings.

- Due to the limitations of the questionnaire, the influence of genetic origin (eye features of individuals) and sociocultural background on daylight perception was not investigated. Further research into the influence of eye characteristics on individual perceptions should be conducted in collaboration with researchers from medical and/or genetic backgrounds. It is also suggested that a detailed interview be conducted with the participants to define the perceptual patterns of people from a similar sociocultural context for future research into the impact of sociocultural context on daylight perception.

- The relationship between the external illuminance of the city where participants spent most of their lives, and their daylight perception should be evaluated with a long-term recording of the amount of daylight exposure. This is because the analysis we performed in this study assumes that the individuals were exposed to similar amounts of daylight in their countries. Thus, more information about how much individuals were exposed to daylight for an extended period of time is required. It is recommended that data on individuals' daylight exposure be collected by asking participants to wear biometric devices for a long period of time. If biometric devices are not feasible, participants may be asked to keep a daily daylight exposure log, and their daylight exposure may be calculated using the proposed light exposure calculation method (See **section 6.2.7.2.**)

- It is also recommended that participants wear biometric devices prior to the study to collect data on the impact of the previous luminous environment, which is the luminous conditions participants were exposed to before the study, on daylight perception. The data gathered by these devices may provide more accurate information than simply asking participants what time of day they are exposed to daylight on regular and free days.

6.4 Summary

Daylighting is an important component of the indoor environment that significantly impacts the occupants' comfort and well-being. When assessing daylighting quality, photometric measurements alone do not fully represent the subjective aspect of the lighting environment; therefore, more attention should be paid to how individuals perceive the same daylight conditions. This chapter aimed to determine whether an individual's cultural background influences how daylight conditions are perceived. A unique methodology was developed to achieve this goal based on the findings presented in the previous chapters, the components defined in the systematic review as cultural background in the lit environment and daylight perception assessment methods in the context of cultural background.

This chapter demonstrated that Asian participants are twice as likely as Whites to perceive daylight conditions lower than actual measurements. On the other hand, it demonstrated that people who spent most of their lives in a city with a lower external illuminance than London perceive daylight conditions in the agreement with actual measurements than those who have lived in cities with higher illuminance. People from cities with higher latitudes, ultimately cities with less daylight availability, appear to overperceive the daylight conditions in the UK, which needs further investigation. Daylight perceptions of people with less daylight exposure in the four weeks preceding the study were more compatible with actual daylight measurements than those with more exposure. On the other hand, people who spent less than a year in London are twice as likely to perceive daylight conditions as being lower than actual measurements compared to those who spend between 12 and 36 months. Even though there was no difference in how various genders perceived daylight conditions, females appear to have a much larger propensity than males (1.7 times) to overperceive the amount of daylight.

This chapter highlighted a remarkable number of people who perceive and describe daylighting conditions that differ from actual measurements, demonstrating that individuals do not describe daylight conditions as real conditions. Intra-individual and inter-individual differences could impact this variation, and this situation highlights the need and potential contribution of this study. Although some findings prove that culture may be an important factor in daylight perception, the study results do not provide strong evidence of a cultural background influence on daylight perception. Even if there are some uncertainties in the influence of cultural background on daylight perception, it seems to need further research. Future research into the impact of daylight exposure in their country on individuals' daylight perceptions should be conducted, with participants wearing biometric devices for extended periods. In the absence of biometric devices, participants may be asked to keep a daily daylight exposure log, and their daylight exposure may be calculated using the proposed light exposure calculation method. It is also recommended that participants wear biometric devices before the study to collect data on the impact of the previous luminous environment or the luminous conditions.

CHAPTER 7: Conclusions and future research

This research project aimed to investigate the influence of cultural background on the subjective assessment of daylight. Each chapter has its own methodology and research activities planned to answer the research questions. Several methods were developed and applied to investigate the relationship between cultural background and daylight perception. This chapter summarises the work presented in the previous chapters, provides overall conclusions and potential implications for the research on daylight perception research and highlights potential areas for future research and practice.

7.1 Conclusions

This thesis comprises seven chapters and a summary of the content and key findings as follows. **CHAPTER 1** gave a brief summary of the study, aims, and research objectives. Following this introductory chapter, **CHAPTER 2** reviewed what is currently known about the impact of daylight on human health and well-being. This chapter also provided an overview of daylight perception to establish the extent to which assessment methods of daylight perception have been used commonly and develop research questions to be investigated. After identification of the evaluation methods for daylight perception, **CHAPTER 3** presented a comparative study to investigate the differences between three subjective evaluation methods compared with actual daylight measurements to understand how participants perceive the daylight conditions and which method closely corresponds to the participants' perception of daylight. In this context, seat preference, subjective ratings, and daylight boundary line drawings were all used as subjective evaluation methods to assess the daylight perception of individuals.

Within this context, an experiment was conducted with 50 students who were instructed to choose the best and worst seats to understand the impact of daylight availability on students' seat selections. Afterwards, students were asked to describe the amount of daylight at the seats selected as best and draw "daylight boundary lines" whenever a significant change of contrast (the distinction between light and dark area) was perceived when moving around the library.

This chapter demonstrated that perceived daylight availability obtained through seat preference and subjective statement methods agrees to some extent with actual daylight availability; there remains a slight difference between participants' statements and actual daylight conditions. The findings from the seat preference method also showed that daylight was the most dominant reason when selecting the best desks in the library, followed by privacy, outdoor view and quietness, respectively. Although the reasons for seat selection varied, the majority of the participants agreed on particular reasons; satisfactory daylighting level, facing the least number of people, and a greenery outdoor view.

On the other hand, participants' perceived daylight availability from daylight boundary line drawings varied extensively from person to person, regardless of actual daylight measurements. This chapter concluded that subjective rating and seat preference methods are suitable for evaluating individuals' daylight perception. Although daylight availability corresponds better with subjective statements, collecting participants' subjective responses would not always be possible, especially in large-scale studies. Therefore, the combination of subjective rating and seat preference methods is suggested as appropriate methods for assessing daylight perception.

However, although most participants stated a satisfactory daylighting level as the most dominant reason when selecting the best desks in the previous chapter, it was limited to the choice of a group of people at a given point in time. Therefore, further analysis was needed to confirm the role of daylight availability in students' seating selection and the suitability of the seat selection method for evaluating daylight perception. **CHAPTER 4** presented a study using the occupancy data of the UCL Bartlett library acquired from motion sensors located underneath each desk. This data was then compared to characteristics of space, including daylight availability.

The study provided evidence that daylight conditions encourage students to select specific desks, as claimed in Chapter 3, by showing that most of the seats selected as the best were located in areas with high illumination. However, the seats with a good combination of daylight, outdoor view, and privacy were in more demand than those with only high daylight levels. It was also demonstrated that the increase in the illumination of the desks is generally followed by higher utilisation in places daylit by side windows rather than skylights. It could be argued that access to outdoor views and favourable daylighting conditions make certain desks preferable than only daylight. Privacy seems to be another critical component because the area lit by skylight is an open-plan space and comparatively less private than other rooms.

The previous chapters purposed to provide an overview of daylight perception to establish the extent to which assessment methods of daylight perception have been commonly used and to develop a methodology to investigate the individual differences in the perception of daylight conditions. Following that, a conceptual framework of cultural background in the lit environment was defined to evaluate the inter-individual differences in daylight perception due to variations in cultural background.

Therefore, **CHAPTER 5** aimed to identify, evaluate, and summarise the findings of all relevant individual studies using a systematic review to create a conceptual framework of cultural background in the lit environment, which could help understand the impact of cultural background on individuals’ daylight perception. This review showed that factors thought to influence daylight perception in the cultural context have been explored in several ways. It firstly demonstrated that ethnicity and/or physiological properties of individual eyes affect daylight perception and preferences. Secondly, it provided evidence for the importance of the residential area's impact on the daylight perception of the people living in the same geographical location and getting used to experiencing those conditions. Secondly, it provided evidence that the participants' residential area influences their daylight perception, assuming that people living in the same geographical location become accustomed to those conditions and thus perceive daylight conditions similarly. Thirdly, it highlighted the importance of the previous luminance environment and suggested that the prior light history should be considered under the combination of outdoor daylight availability and the subject's lifestyle. Lastly, it stated that sociocultural background and related behaviour patterns impact daylight perception within the individual and contextual variability. Together these results provide valuable insights into daylight perception in the cultural context.

This chapter confirmed the assumption that there are differences in how people perceive and feel about lighting conditions due to their cultural backgrounds with various approaches. It also emphasised the lack of comprehensive knowledge of this issue regarding the perceived adequacy of illumination for people from different cultural backgrounds.

Following the definition of cultural background on daylight perception, **CHAPTER 6** established a methodology and reported the findings of a study where daylight perception in the context of the cultural background was assessed. This chapter demonstrated that Asian participants are twice as likely as Whites to underperceive, namely, perceive daylight conditions lower than actual measurements. On the other hand, it demonstrated that people who spent most of their lives in a city with a lower external illuminance than London perceive daylight conditions that are more compatible with actual measurements than those who lived in a city with a higher illuminance. People from cities with higher latitudes, ultimately cities with less daylight availability, also appeared to overperceive the daylight conditions in the UK, which needs further investigation. Daylight perceptions of people with less daylight exposure during the four weeks preceding the study were more compatible with actual daylight measurements than those with more exposure. On the other hand, people who spent less than a year in London are twice as likely to perceive daylight conditions as being lower than actual measurements compared to those who spend between 12 and 36 months. Even though there was no difference in gender and perceived daylight conditions, females appear to have a much larger propensity than males (1.7 times) to overperceive the amount of daylight.

This chapter demonstrated that individuals do not always describe daylight conditions as measured. Intra-individual and inter-individual differences could impact this variation, and this situation highlights this study's need and potential contribution.

Although some findings prove that culture may be an important factor in daylight perception, the study results do not provide strong evidence of the cultural background influence on daylight perception. Even if there are some uncertainties in the influence of cultural background on daylight perception, it seems to need further research.

However, the goal of this research project was to conduct a consecutive study with different sample sizes. The first research project proposed for Chapter 6 was carried out at the Bartlett Library with 193 students to evaluate preliminary findings and the developed methodology, and it was successfully completed and reported in the thesis. The following research activity was planned to extend the previous study to all UCL libraries to reach as many students from diverse cultural backgrounds as possible. However, planned research activities were disrupted due to Covid-19. Therefore, it was impossible to undertake fieldwork due to the lack of and reduced access to UCL libraries. Although a few libraries were later reopened, specific seat places were restricted to maintain social distance, significantly influencing the study's findings while limiting available seat options. In addition, the number of students preferring to study in libraries was significantly lower than usual. Finally,
CHAPTER 7 summarised the work presented in the previous chapters, provides overall conclusions and potential implications for the research on daylight perception research and highlights potential areas for future research and practice.

The purpose of this thesis was to investigate whether individuals perceive daylight conditions differently from each other due to their cultural backgrounds. The thesis seeks to address three research questions in order to achieve its goal. The research questions and answers are as follows:

RQ1. What are the most commonly used methods for assessing individuals' daylight perception?

In this thesis, **Chapter 2** aimed to identify the commonly used methods for assessing daylight perception to develop a methodology to investigate the impact of cultural background on daylight perception in the following stage. For this aim, the methodological approach of 482 research articles were reviewed and the assessment methods for daylight perception was divided into three groups; as subjective assessment methods, physiological assessment methods and assessment of circadian daylight.

This review showed that although most methods and tools used in assessing daylight perception differ, their general methodological approach is similar; they combine subjective and objective measurements and assess them depending on the existing lighting conditions collected by either spot measurements or daylighting simulations. The studies are also often supported by circadian rhythm parameters, such as cognitive performance, alertness, sleep quality, and mood. Nevertheless, almost all studies have used one or more methods to assess the changes occurring in daylight perception concerning the variation in the luminous environment. Furthermore, **Chapters 3 and 4** demonstrated that subjective rating and seat preference methods, as subjective assessment methods, could be used to evaluate daylight perception.

RQ2. What does “culture” mean, and what are the key elements of cultural background in the lighting environment?

In this thesis, **Chapter 5** aimed to create a conceptual framework of cultural background in the lighting environment to investigate an association between cultural background and daylight perception. The systematic review conducted in Chapter 5 showed that factors thought to be influencing daylight perception in the cultural context have been explored in several ways.

It firstly demonstrated that **ethnicity and/or physiological properties of individual eyes** affect daylight perception and preferences. Secondly, it provided evidence that the participants' **residential area** influences their daylight perception on the assumption that people living in the same geographical location become accustomed to those conditions and thus perceive daylight conditions similarly. Thirdly, it remarked on the importance of **the previous luminance environment** and suggested that the prior light history should be considered under the combination of outdoor daylight availability and the subject's lifestyle and preferences. Lastly, it stated that **sociocultural background** and possibly related behavioural patterns impact daylight perception within the individual and contextual variability. Together these results provide valuable insights into daylight perception in the cultural context.

RQ3. Does cultural background affect how people perceive daylight, and if so, how?

Chapter 6 aimed to determine whether an individual's cultural background influences how daylight conditions are perceived. A unique methodology was developed to achieve this goal based on the previous findings in this thesis, the components defined in the systematic review as cultural background in the lit environment and daylight perception assessment methods in the context of cultural background. For this aim, 193 students who had already been studying in the Bartlett library were randomly approached and asked if they were interested in participating in the study. In order to assess the participants' subjective responses, they were asked to fill out a semi-structured questionnaire, which included a section for rating the amount of daylight availability at their desks, synchronously quantifying the horizontal illuminance on the desk with an illuminance meter by the researcher. Then, participants' perceptions and actual daylight availability on their desks were compared using the cultural background components.

In this study, the influence of sociocultural background and eye characteristics of individuals on their daylight perception were not investigated. Because the influence of eye characteristics on individual perception required a collaborative study with researchers from a medical or genetic background. Also, a detailed interviewing was needed to define the perceptual patterns of people from a similar sociocultural context which was not possible to conduct due to COVID-19.

This chapter demonstrated that Asian participants are twice as likely as Whites to perceive daylight conditions lower than actual measurements. On the other hand, it demonstrated that people who spent most of their lives in a city with a lower external illuminance than London perceive daylight conditions in the agreement with actual measurements than those who have lived in cities with higher illuminance. People from cities with higher latitudes, ultimately cities with less daylight availability, appear to overperceive the daylight conditions in the UK, which needs further investigation. Daylight perceptions of people with less daylight exposure in the four weeks preceding the study were more compatible with actual daylight measurements than those with more exposure. On the other hand, people who spent less than a year in

London are twice as likely to perceive daylight conditions as being lower than actual measurements compared to those who spend between 12 and 36 months. Even though there was no difference in how various genders perceived daylight conditions, females appear to have a higher tendency than males to overperceive the amount of daylight.

This chapter highlighted a remarkable number of people who perceive and describe daylighting conditions that differ from actual measurements. Intra-individual and inter-individual differences could impact this variation, and this situation highlights the need and potential contribution of this study. Although some findings prove that culture may be an important factor in daylight perception, the study results do not provide a strong evidence of a cultural background influence on daylight perception. Even if there are some uncertainties in the influence of cultural background on daylight perception, it seems to need further research.

7.2 Limitations

A summary of the main limitations of this research project is presented below. These limitations have already been described in detail in the specific chapters:

- **Restricted access to libraries and participants:** Following the study presented in Chapter 6, subsequent research activity was planned to extend the study to all UCL libraries and test the developed methodology in different library buildings to reach as many students as possible from diverse cultural backgrounds. However, planned research activities were disrupted due to Covid-19 inability to undertake fieldwork due to lack of and reduced access to UCL libraries.

- **Limited to a particular library:** The current findings are a snapshot of time and space. The extent to which the proposed methods can be used in different contexts, that is, for different types of library buildings with various daylighting design strategies and different groups of people, deserves future attention. The spaces and characteristics of the desks in different kinds of library buildings could greatly impact the participants' seat selections. However, due to Covid-19 restrictions to access to other libraries, the extension of the application of the developed methodology to other UCL libraries was not possible. Therefore, the study was limited to a particular place and group of people at a given time, and all studies in the thesis were conducted in the UCL Bartlett Library.

    - **Student characteristics:** Students from different educational backgrounds could prefer different libraries due to accessibility to resources in their fields and the closeness of the library to their formal lectures and tutorials. There are various libraries at the UCL, covering a wide range of specialist subjects ranging from biomedicine and science to arts, architecture and archaeology. Therefore, a library providing students with specific resources would be preferable for those students' academic-related backgrounds. For instance, the Bartlett Library is mainly used by students from architecture because it holds a collection including architecture, planning, development planning, construction and project management, sustainable energy and sustainable resources, as well as the social and cultural history of cities and urban spaces. As a result, selection bias can lead to inaccuracies in the study. For instance, this study was conducted in the Bartlett Library with mainly architecture students with a potentially higher awareness of architectural and natural elements in a building than students from other educational backgrounds. This situation might have potentially affected the students' seat selection reasons. Therefore, the role of daylight availability in students' seat selection would be different when the same procedure was applied to other libraries.

- **Limited to activity:** The role of daylight availability on seat selection may vary depending on the context, sample characteristics, and also the activities participants are requested to undertake. For instance, in the study presented in Chapter 3, students were brought all together to the Bartlett Library and asked to choose the location of the three best and three worst seats from the library's seating plan and the most and least liked within those categories. Study results could have been different if the participants were in real need of using the space for their respective tasks (e.g., reading and writing for an assignment) instead of being in the library for the experiment. In that case, privacy and quietness could have been more important than lighting or outdoor view. As a result, limiting participants to a single activity may have influenced their attention, space assessment, and, in turn, seat preferences in the library.

- **Limited data collection from motion sensors:** As presented in Chapter 4, occupancy data from motion sensors located underneath each desk in the Bartlett library was used in the analysis. Although the data collected through the sensors indicate whether the space was in use or not, each sensor can only report on the availability of the desk and cannot collect personal data or identify an individual. The collected information is binary: either somebody has sat there at a specific time or has not. Therefore, study results do not represent students' personalities, individual perceptions and expectations. We do not know who that somebody is, nor can we identify if the person sitting there now is different from the last time we checked the sensor's status.

- **Limited freedom of choice:** Occupancy is not always based on human presence. Students occasionally leave their laptops, water bottles, and backpacks to claim a seat while they go outside. PIR sensors can not detect a claimed seat due to no large heat signatures or movement. This situation could affect students' freedom of choice and, ultimately, the interpretation of seat selection of students. This is because motion sensors assume that the desk is available in the case of no movement, but in reality, the desks could have been occupied with student's belongings, not allowing others to select them.

- **Out-of-order sensors:** Another limitation could result from the assumption that all sensors were working properly during the period selected for the analysis. The visualisation instrument of occupancy data obtained from motion sensors does not give information about the working status of the sensors. When sensors are out of order, they are regarded as unoccupied, which could significantly impact the interpretation of the findings.

7.3 Contributions

This thesis has several contributions to the current state of knowledge in the following ways:

- **Gaining a better understanding of daylight perception:** The most significant contribution of this research is to provide a better understanding of the factors that could play a role in the daylight perception of participants, particularly cultural background. Increasing the knowledge of individuals' perceptions will help us provide lighting conditions that meet their needs and expectations, making them more satisfied with the indoor conditions in the built environment. Gaining a better understanding of students' daylight perception and expectations could increase their satisfaction with the indoor environment and improve their cognitive and academic performance. This could be especially important for students who migrate for studying purposes for a short period of time (e.g. MSc students) to assist them in adapting to a new environment and focusing on their studies as quickly as possible.

- **Filling the gaps in the literature:** There has been very little research on “Assessment methods of daylight perception” and “The interaction between daylight availability and students’ seating selection, " which are topics not extensively investigated. Several experiments and analyses were conducted on those topics as part of this research project, and a couple of research papers were produced from them. On the other hand, the term of “culture” was not defined previously in the lighting context and was not the subject of a study. In the thesis, factors that are thought to affect daylight perception in the context of culture have been investigated in a variety of ways, and these components were then used in an experiment. In addition, many studies on cultural issues in the lighting field only take into account the participants' glare sensitivity and not the intensity of the daylight. This is the first study approaching the cultural background of participants considering their evaluation of daylight intensity. Due to the lack of knowledge in the literature, this research project also required the development of a number of methodologies, assessment methods and theoretical backgrounds to fill the gaps in the literature.

- **Development of methods in the lighting field:** The contribution of this study is not limited to the literature but also the development of unique assessment methods in the lighting field. For example, because of the fluctuating illuminance levels, random experiments with large sample sizes were uncommon in lighting studies, but in this study, a simplified methodology was developed to assess individuals' daylight perception without needing an experiment. On the other hand, the role of daylight availability in students' seat selection was examined in a way that has not previously been done by benefitting from both occupants' selections and occupancy data from motion sensors. This allowed data from these two methods to be compared and more robust conclusions about the students' seating behaviour. Also, various assessment methods were developed based on previous research in the lighting field, such as the development of the method for daylight exposure of participants, assessment method of daylight availability in cities where participants lived and assessment method of individuals' daylight perception.

- **Increasing awareness of cultural background in the lighting context:** Users are generally not considered a main factor during the building design stage. However, this study showed that the cultural background of occupants could be important to maintaining their satisfaction with the lighting conditions in an indoor environment.

7.4 Future research and practical applications

7.4.1. Recommendations for future research

- **Larger sample size:** Further studies are recommended to use the developed methodology with a large sample size of participants to generalize the findings to the population. The findings obtained in this investigation should be validated in future investigations with participants from different climatic-cultural context, educational background, gender, and age range.

- **Differentiation between daylight conditions and outdoor view:** Preferences for window seats are, to some degree, dependent on the presence of an outside view. It is important to differentiate if participants selected desks nearby windows due to daylight availability, outdoor view, or both. In order to remove the outside view as a variable factor in the link between daylight and students' seat preferences, this study could be repeated in the same procedure for examining the role of the outdoor view in students' seat selections. Alternatively, the same procedure could be conducted in spaces lit solely by skylights, in which case the differences in seating behaviour due to the presence of outside view would be expected to disappear.

- **Using high dynamic range (HDR) imaging techniques:** Future research on the impact of cultural background on daylight perception could use high dynamic range (HDR) imaging techniques that allow the required luminance range to be created. In the further development of these techniques, subjective daylight perception under various computer-generated conditions could be assessed using scenes displayed with the Immersive virtual reality (VR) technique.

- **Considering the occupants' cultural background:** This study showed that the cultural background of occupants could play an important role in maintaining their satisfaction with the lighting conditions in an indoor environment. However, further study is suggested on the cultural background of occupants, taking into account not only daylight conditions but also other factors as an essential part of the indoor environmental quality such as thermal conditions, air quality etc.

- **Considering other reasons for seat selection along with daylight:** Future research should also consider the impact of other environmental parameters on seat preference and how they relate to lighting conditions to improve occupant satisfaction. The interaction between any parameter and seating choice of students should not be examined in isolation; other aspects, such as privacy, outdoor view and quietness, should also be considered in addition to daylight. In the literature, there is no developed methodology for evaluating and rating the library seats in terms of various characteristics. Therefore, it is suggested to give points to each desk in terms of various aspects such as daylight, outdoor view, privacy, quietness etc. and assess the occupancy of the library seats based on them.

The indoor environment includes a variety of environmental factors, and the impact of confounding indoor environment factors (e.g., indoor air quality, thermal comfort) on outcomes should be thoroughly considered in order to avoid interpretation of bias. For instance, when a student prefers a desk not getting directly daylight at a place far away from the window may result from air leaks near the window which causes feeling cold when she sits near the window. In this case, relying solely on desk utilisation and daylight availability in the space may lead to the incorrect conclusion that the student does not prefer a desk with daylight and an outdoor view. Similarly, a student may dislike a desk in a small space due to poor indoor air quality, but this cannot be determined without objective measurements. Therefore, during the experiments, each environmental factor in the indoor environment should be measured, and reasons leading the students’ seating selection should be thoroughly examined because preferences do not contain a single reason, but rather a combination of them.

- **Detailed research in genetic origin and sociocultural background:** The influence of genetic origin (eye features of individuals) and sociocultural background on daylight perception was not investigated. Further research into the influence of eye characteristics on individual perceptions should be conducted in collaboration with researchers from medical and/or genetic backgrounds. It is also suggested that a detailed interview be conducted with the participants to define the perceptual patterns of people from a similar sociocultural context for future research into the impact of sociocultural context on daylight perception.

- **Long-term recording of the amount of daylight exposure:** The relationship between the external illuminance of the city where participants spent most of their lives, and their daylight perception should be evaluated with a long-term recording of the amount of daylight exposure. This is because the analysis we performed in this study assumes that the individuals were exposed to similar amounts of daylight in their countries. Thus, more information about how much individuals were exposed to daylight for an extended period of time is required. It is recommended that data on individuals' daylight exposure be collected by asking participants to wear biometric devices for a long period of time. If biometric devices are not feasible, participants may be asked to keep a daily daylight exposure log, and their daylight exposure could be calculated using the proposed light exposure calculation method in this study based on participants' subjective statements. However, this calculation method needs verification with actual measurements in future research. In the absence of biometric devices, this method could also be an opportunity for researchers to investigate the impact of daylight exposure on participants' mood, willingness to work, and so on.

- **Wearing biometric devices for exposed daylight exposure:** It is also recommended that participants wear biometric devices before the study to collect data on the impact of the previous luminous environment, which is the luminous conditions participants were exposed to before the study, on daylight perception. The data gathered by these devices may provide more accurate information than simply asking participants what time of day they are exposed to daylight on regular and free days.

7.4.2. Practical applications of research findings

- **Application of the developed methodology to other studies:** The developed methodology that aims to understand the role of daylight availability in students’ seat selection could be applied to other research studies for different purposes. For example, the developed postdoctoral research project seen in **Appendix 7.5** aims to increase students’ feeling of belonging to libraries and improve their satisfaction and learning performance considering various indoor and personal components. Although the same procedure in this study is applied to other libraries, the scope of this study also covers other indoor elements, thermal comfort, outdoor view, noise etc., in addition to daylight availability.

- **Developing strategies for saving energy:** Understanding the role of occupant behaviour in the built environment and investigating the occupants’ interactions with the indoor environment could help to improve occupants’ satisfaction [121] as well as energy efficiency in a building [122] [123]. For instance, understanding the factors influencing the occupants’ interaction with electric lighting (patterns of turning artificial lights on and off) could help minimize the performance gap between predicted and operational lighting consumption as well as maintain the occupants’ satisfaction with the built environment [143]. Research conducted in Korean office buildings with the application of automatic dimming control for lighting with a design illuminance of occupants’ expectations and usage habits helped to reduce lighting energy consumption by up to 43% [23]. However, due to the complexity and variety in the factors of potential influence on occupant behaviours such as lifestyle, demography, economy, interaction with building features and equipment, predicting beforehand building occupancy behaviour and buildings’ energy use could become problematic in general and on occupants in particular [125]. Having knowledge about occupants’ lighting expectations due to their cultural background could also help meet the occupants’ needs and preferences and provide occupant satisfaction, which in turn helps reduce unnecessary energy consumption in the built environment. Therefore, this knowledge can also be utilised by managers and daily operators of university buildings to help reduce the energy consumption of HVAC (Heating, Ventilation, and Air Conditioning) and illumination systems. More research into developing energy-saving strategies resulting from meeting occupants' needs and expectations is required. One of the strategies to save energy could be replacing the bulbs in the libraries based on the level of lighting students expect from the library environment, activation of the manual control of the lights and raising lighting energy conservation awareness of occupants. Another strategy could be turning the lights off automatically when motion sensors do not detect any movement in the specific place. In this way, it is possible to reduce a building's electrical energy consumption by 25-40%. In this strategy, the level of lighting could be adjusted to meet the students' needs and expectations from the library environment. Also, daylight sensors could be installed especially in south and east directions to consider the daylight intensity on an area and adjust the electric lighting automatically by dimming lights or turning off a portion of the lights, in order to maintain a consistent illumination level of an area to create a comfortable environment and reduce electrical energy waste from over lit spaces.

- **Rearrangement of opening hours in libraries:** Total energy consumption of the library could be reduced when the opening hours are rearranged depending on the hours when a room is primarily vacant or occupied by a few people. In this way, managers could have a chance to investigate the reasons behind lowly-utilised desks and spaces. They could set up a new lighting control that matches actual building occupancy more closely than current settings, and even some rooms could be closed during the lowly utilised period to reduce unnecessary energy consumption in UCL libraries.

- **Considering the cultural background in daylight design guidelines:** Daylighting codes and standards were developed primarily with visual task requirements but with a limited scientific understanding of the role of cultural background in occupants' daylight perceptions and preferences. Namely, recommended standards for illumination levels in libraries do not represent the differences in daylight perception of individuals from different cultural backgrounds. Therefore, some findings are suggested for further development in the design guidelines for daylighting design.

Recommendations of sunlight levels, view out, daylight provision, and glare protection in buildings are often proposed by daylight standards such as European EN 17037:2018, however specific local contexts and cultural background of residents are not factors normally considered by the majority of current daylight standards. These daylight standards only provide the minimum requirements to achieve a certain level of daylight performance and do not provide recommendations to adapt the minimum requirements based on cultural context. It could be problematic to compare the findings in a single-context daylight study to different cultural-climatic contexts, therefore, the daylight standards should include thresholds depending on the cultural and climatic context. They should also provide the optimal level of daylight for each cultural context, not just the minimum requirements. The cultural context should not be limited to climatic conditions; ethnic background, cultural norms, and values of residents should also be taken into account when designing the thresholds as highlighted in this study. Although individual variations make a difference in the perception of daylight, setting thresholds based on cultural context could still benefit residents living in the same location.

- **Designing layouts in libraries:** The insights gained in this research have potentially important implications for daylighting design of library buildings as well as for understanding the relationship between daylighting and human behaviour. Therefore, it can support architects and lighting professionals working in the design of library buildings. The findings of this study and further studies derived from it could be used to understand how the layout of the spaces in library buildings could be improved to create a more pleasant workspace.

- **Seating arrangements for libraries:** Especially for architects, it is crucial to understand and consider the factors that influence human behaviour in a library because being aware of users' preferences makes it possible to design functional, comfortable and high-quality spaces. Understanding seat selection behaviour can potentially contribute to an awareness of human dimensions, spatial organisation, and space management during the design process. The study results can contribute to understanding the role of daylight on seat preference alongside other factors and help design seat arrangements in libraries. The results can help designers consider not only the shape of the building but also seating spaces providing different characteristics of space for students during the design stage.

Competing Interests

The author declares that she has no conflicts of interest to declare.

Ethics approval and consent to participate

The researcher created a semi-structured questionnaire that was approved by Jonathan Taylor, a member of the Ethical Committee of the University College London, the Bartlett School, Institute of Environmental Design and Engineering. The ethical approval for this study was obtained from the UCL Research Ethics Committee on 02/12/2019, as seen in below BSEER Ethics Review form.

UCL

THE BARTLETT SCHOOL OF ENVIRONMENT, ENERGY AND RESOURCES

BSEER Research Ethics – Low Risk Application – Review (v1.11)

Applicant UCL email address: gizem.izmir.tunahan.17@ucl.ac.uk
Energy Institute / IEDE / ISH / ISR (Cross out as applicable)
Student / Staff (Cross out as applicable)
(If Student) **Course: PhD**
(If Student) **Supervisor: Hector Altamirano/Jemima Unwin**
(If Staff) **Principal Investigator:**
Title of Study: The impact of cultural background on daylight perception
Date of Application: 02/12/2019

	Unsatisfactory	Satisfactory	N/A
STUDY DETAILS			
Sufficient study details provided to evaluate ethical implications		x	
Study does not seem to include sensitive topics (see High Risk checklist)		x	
Sufficient sampling details provided to evaluate ethical implications		x	
Sample does not seem to include vulnerable individuals (see High Risk checklist) & active steps to exclude <18yo		x	
CONSENT			
Information for participants covers necessary issues adequately (Researcher & says if student, Institution, funder, study title & purpose, how participant selected, excludes <18yo, what happens to participant, how long it will take, benefits, potential risks/harms, anonymity/confidentiality, voluntariness, right to withdraw, contact details)		x	
Information for participants is sufficiently concise		x	
Information for participants is written in an appropriate style (Study title and content appropriately phrased for participants, level of detail appropriate for participants)		x	
(Where participants known to researcher) appropriate procedures to ensure participants feel free to not participate & withdraw from the study		x	
EVALUATION & MITIGATION OF HARM			
Risk of harm to participants seems to be minimal (see High Risk checklist)		x	
Recognises & addresses potential risks/harms to participants		x	
(Where risks to researcher beyond those experienced in daily life) has appropriate risk assessment been completed?			x
DATA PROTECTION & PRIVACY			
Correctly identifies whether/not personal data are being collected / used / processed (Definition of personal data is embedded in the low risk form Q42…check whole application to ensure applicant answered this Q correctly)		x	
Correctly identifies whether/not *special category* or *criminal records* personal data are being collected / used / processed (Definitions embedded in the low risk form Q43…check whole application to ensure applicant answered this Q correctly)		x	
(If personal data are being collected / used / processed) has registered study with UCL Data Protection Officer			x
(Where participants are known to researcher) appropriate procedures to protect participants' privacy (EG data collected &/or collection method)		x	

Review (delete as applicable):
x Study is low risk and may commence.
☐ Study is low risk and may commence AFTER you obtain a UCL Data Protection number from UCL Legal – you are collecting personal data
☐ Study is low risk and may commence AFTER you meet the following conditions and demonstrate that to the evaluators:
☐ Study requires revised submission to BSEER Research Ethics Team. Data collection/processing cannot start until the research is evaluated as low risk.
☐ Study requires approval from UCL Research Ethics Committee prior to data collection/processing.
Name(s) of BSEER reviewer(s): Jonathon Taylor
Date: 02/12/2019

The consent form below was created and asked participants to give their permission to participate in the research, along with an additional information sheet about the study's details.

Bartlett School Environment,
Energy and Resources
Upper Woburn Place
WC1H ONN London

Project Title: **The impact of cultural background on daylight perception**

Researcher: **Gizem Izmir Tunahan**

Thank you for your interest in taking part in this research. Before you agree to take part, the person organizing the research must explain the project to you.

If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you to decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

Participant's Statement

I agree that:

- I have read the notes written above and the Information Sheet, and understand what the study involves.
- I understand that if I decide at any time that I no longer wish to take part in this project, I can notify the researchers involved and withdraw immediately.
- I consent to the processing of my personal information for the purposes of this research study.
- I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.
- I agree that the research project named above has been explained to me to my satisfaction and I agree to take part in this study.

Name of participant:

Signature: Date:

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Authors’ contributions

The PhD candidate, Gizem Izmir Tunahan, designed the study, performed data management, conducted the data analysis, wrote the first draft of the manuscript and implemented the contribution of the supervisors and external reviewers up to final publication. During the whole process, she asked for and implemented input and feedback from the other contributors to this study.

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Appendices

Appendix 1: Details of the rooms and technical properties in the library

		Room 1	Room 2	Room 3
Room geometry (m)	Depth	6.50	19.30	15.20
	Width	4.70	10.30	7.00
	Height	2.81	3.75	2.79
Room reflectance	Floor (carpet)	0.03	0.03	0.03
	Walls	0.85 and 0.24	0.77	0.85
	Ceiling	0.79	0.79	0.79
	Window frame	0.81	0.81	-
Furniture reflectance	Desk	0.64	0.23	0.67
	Territory element	0.06 and 0.10	0.50	0.13
	Bookshelves	-	0.27	-
Opening geometry (m)	Number of openings	2 windows	13 windows	2 skylights
	Height x Width	1.99 x 1.25	2.58 x 1.25 and 2.58 x 1.68	-
	Width x Depth	-	-	3.20 x 6 and 3.20 x 1.80
Glazing characteristics	Visible transmission	0.60	0.60	0.60
Blinds		No	Yes – Occupancy controlled internal blinds	No
Orientation		N	N - E	-
Outdoor view characteristics		Church	Church and back building facade	Only sky view

Appendix 2: The questionnaire used for the research project in Chapter 3

Bartlett School Environment, Energy and Resources
Upper Woburn Place WC1H ONN London

UCL

I'm a PhD student under supervision of Dr. Hector Altamirano and Dr. Jemima Unwin. I would like to invite you to participate in my research project. I'm looking for students coming from different countries and regions, correspondingly, different climate conditions.
If you decide to participate, I will ask you to fill this brief questionnaire which should take around 10-15 minutes. Thank you for taking the time to consider participating in this study. Please do not hesitate to send me questions you may have.

❑ I agree that the research project has been explained to me and I agree to take part in this study.

Gizem Izmir Tunahan
Email: gizem.izmir.tunahan.17@ucl.ac.uk

1. Gender

❑ Male ❑ Female ❑ Other: ______ ❑ Prefer not to say

2. Age

❑ <20 ❑ 20-24 ❑ 25-29 ❑ 30-34 ❑ >35

3. Approximately how long have you been in or around London?

____years ____months ❑ I am a visitor: ____days

4. How would you describe your ethnicity?
(Please, **choose** one section and then, **select** one option to best describe your ethnic group or background)

- ❑ **White:** British, English, Northern Irish, Scottish or Welsh, Irish, Gypsy or Irish traveller, Any other White ethnic group: __________
- ❑ **Mixed/Multiple ethnic groups:** White and Black Caribbean, White and Black African, White and Asian, Any other Mixed or Multiple ethnic group: __________
- ❑ **Asian/Asian British:** Indian, Pakistani, Bangladeshi, Chinese, Any other Asian: __________
- ❑ **Black/African/Caribbean/Black British:** Caribbean, African, Any other Black / African / Caribbean: __________
- ❑ **Other ethnic groups:** Arab, Any other ethnic group: __________

5. How do you describe your cultural background? ______________________

6. Please, fill out the blanks below (Please, indicate **the most specific place**)

	COUNTRY		CITY	
Where were you **born?**				
Where are your **parents** from?	Mother	Father	Mother	Father
Where did you live for **most of** your life?				
	How long:			
Where did you live **in the last year** before coming to London? (If you lived in **multiple places**, please fill all blanks with specific time durations) (Please indicate initially, most current one)				
	How long:			
	How long:			

7. How many days do you have a regular work schedule?
(regular work days are defined as the days you wake up and go to sleep at similar times)

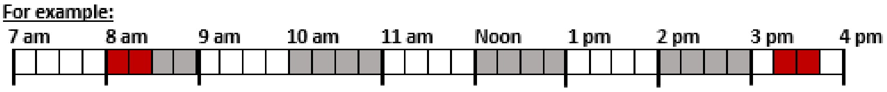
I work on ❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 days per week

8. Can you report on your typical sleep behaviour over the past 4 weeks?
Please, respond to the questions according to your perception of a standard week that includes your usual work days and work-free days and use a 24-hour time scale (e.g. 23:00 instead of 11 pm).

WORKDAYS	FREE DAYS
I go to bed at ______ **o'clock.** (Note that some people stay awake for some time when in bed)	I go to bed at ______ **o'clock.** (Note that some people stay awake for some time when in bed)
I actually get ready to fall asleep at ______ **o'clock.**	I actually get ready to fall asleep at ______ **o'clock.**
I need ____ **minutes** to fall asleep.	I need ____ **minutes** to fall asleep.
I wake up at ______ **o'clock.**	I wake up at ______ **o'clock.**
After ____ **minutes** later, I get up.	After ____ **minutes** later, I get up.
I use an **alarm clock** on workdays: ❑ Yes ❑ No	I use an **alarm clock** on free days: ❑ Yes ❑ No
If yes, I regularly wake up **before** the alarm rings ❑ Yes ❑ No	

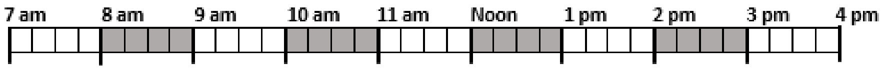
9. Please, fill the gap describing your exposure to natural light outdoors on average **<u>during a typical day in the last 4 weeks.</u>** (without a roof above your head) (each cell represents **<u>15 minutes</u>**)

<u>For example:</u>

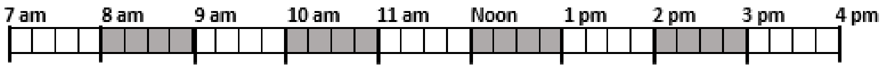


"I spent time outside under the sky at 8:00-8:30 and 3:15-3:45 in a typical day of my last 4 weeks."

<u>On workdays:</u>



<u>On free days:</u>



10. Please walk through the Bartlett Library rooms and identify three best and three worst places to sit down in the below plan drawing (Please tick the point describing that individual desk and write down your liking range. (**A,B,C: best** and **1,2,3: worst** with liking order. A is the most liked one and C is the third. 1 is the least liked and 3 is the third least liked one)

Also, please indicate your reasons for seat preference:

	Best places	Worst places
The reason	A:	1:
	B:	2:
	C:	3:

Please, write down current date and time accurately.

DATE:

TIME:

Please, **tick** the most representative answers to reply following questions for **your A seat preference** which you defined as the best place in the previous question:

11. How do you describe **the amount of daylight** at your seat/ on your desk?

Very low	Low	Below average	Above average	High	Very high
☐	☐	☐	☐	☐	☐

12. How do you describe **the uniformity of daylight** in this room?
(The uniformity of daylight represents if daylight varies within the room or not. If it is uniform, it means that you perceive similar features of daylight amount within all parts of the room)

Very low	Low	Below average	Above average	High	Very high
☐	☐	☐	☐	☐	☐

13. How do you describe **the degree of glare** that you experience when viewing the windows?
(Glare is a visual sensation caused by excessive and uncontrolled brightness)

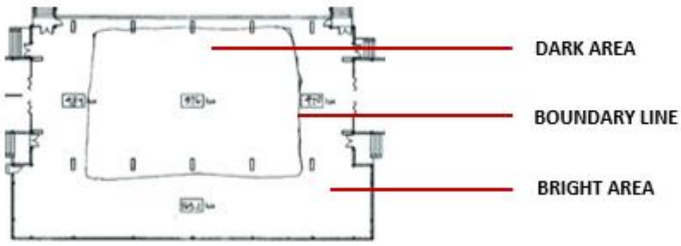
Very low	Low	Below average	Above average	High	Very high
☐	☐	☐	☐	☐	☐

14. How do you feel about your **overall level of visual comfort** in this room?

Very dissatisfied	Moderately dissatisfied	Slightly dissatisfied	Slightly Satisfied	Moderately satisfied	Very satisfied
☐	☐	☐	☐	☐	☐

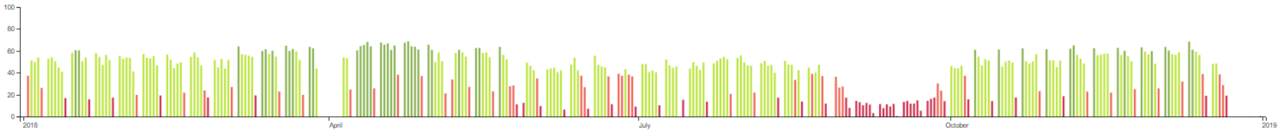
15. Please draw a **'daylight boundary line' for each room** around the area you perceived as bright whenever you find a significant change of contrast. (whenever you feel a change from dark to bright)

For example:

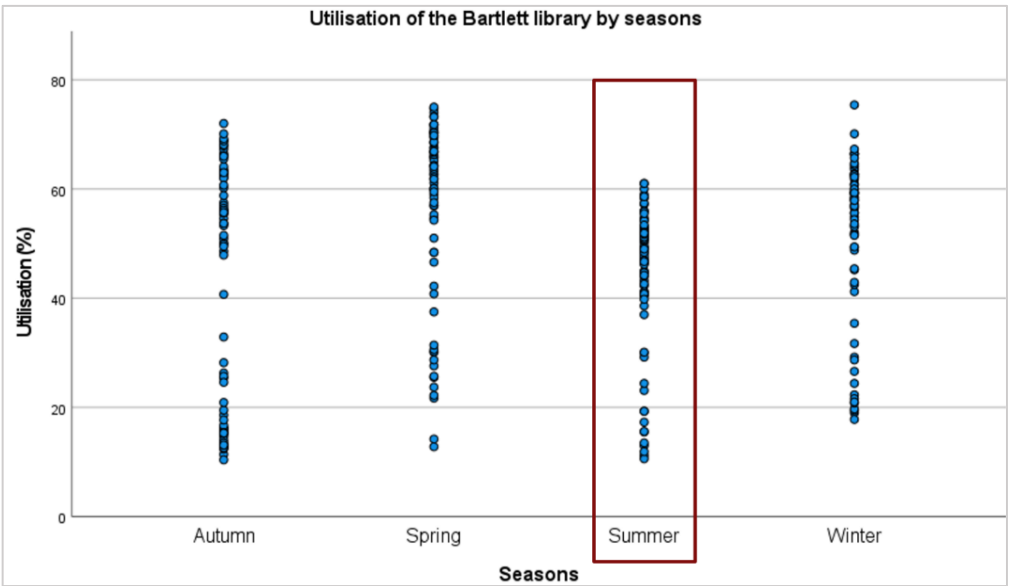


Appendix 3: Description of the occupancy data

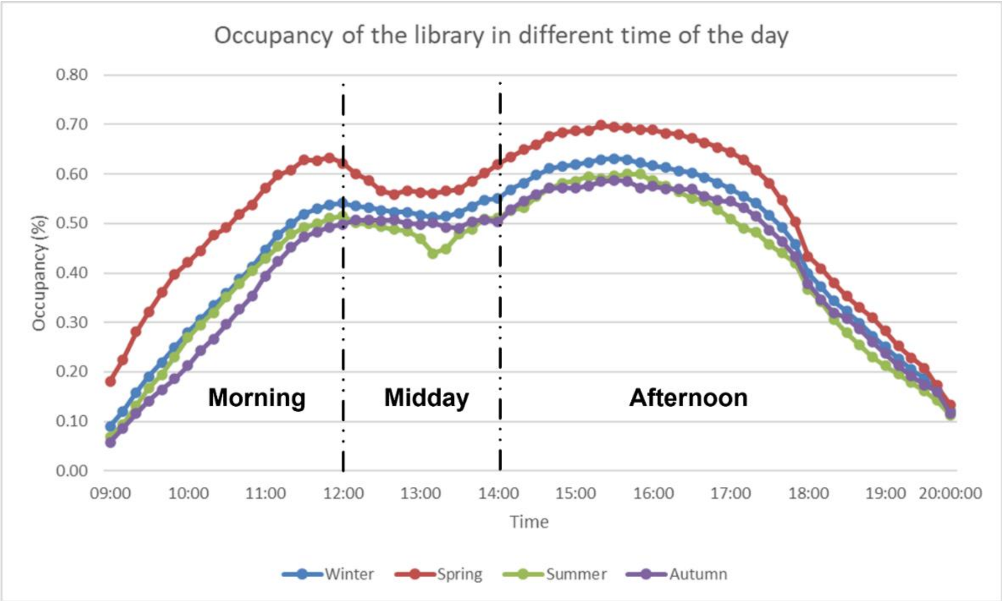
Appendix 3.1: Utilisation of the Bartlett Library by date between 2018 and 2019



Appendix 3.2: Utilisation of the desks in the Bartlett Library in different seasons



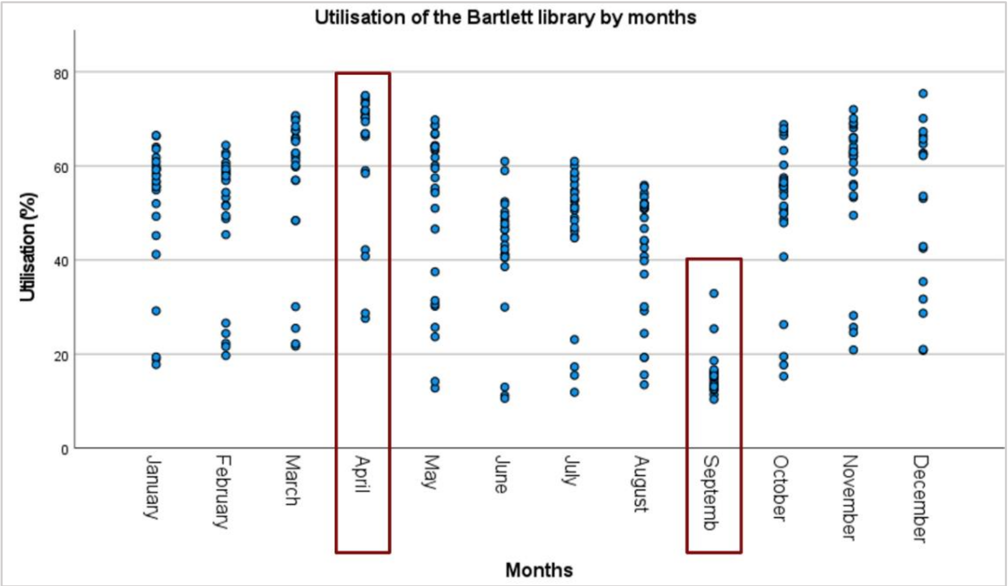
Appendix 3.3: Utilisation of the Bartlett Library in seasons by the time between 2018 and 2019



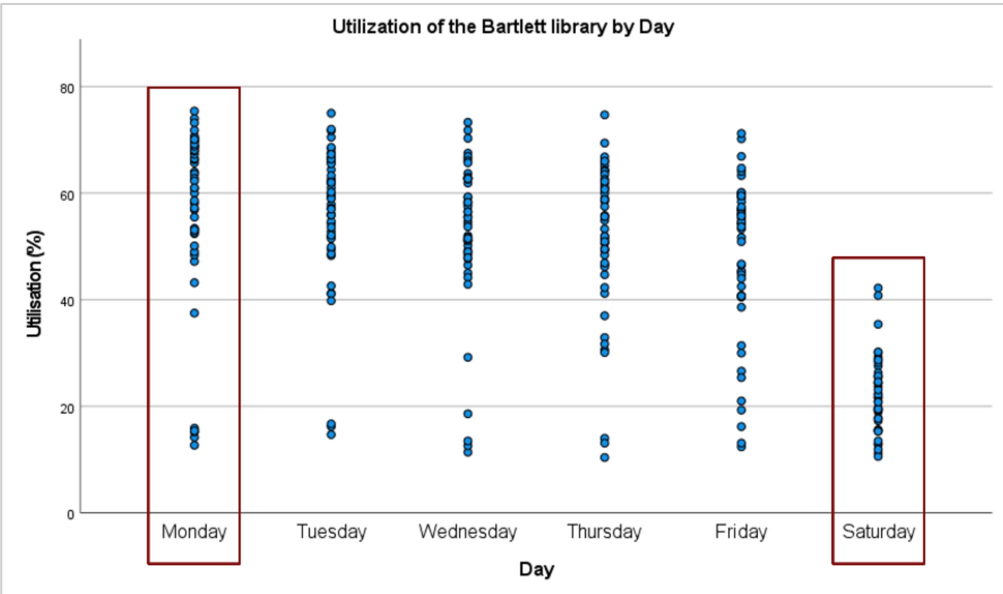
Appendix 3.4: Utilisation of the Bartlett Library at different times of the day in different seasons

Time of day	Winter	Spring	Summer	Autumn
Morning	0.34	0.46	0.32	0.29
Midday	0.53	0.58	0.48	0.50
Afternoon	0.48	0.53	0.44	0.45

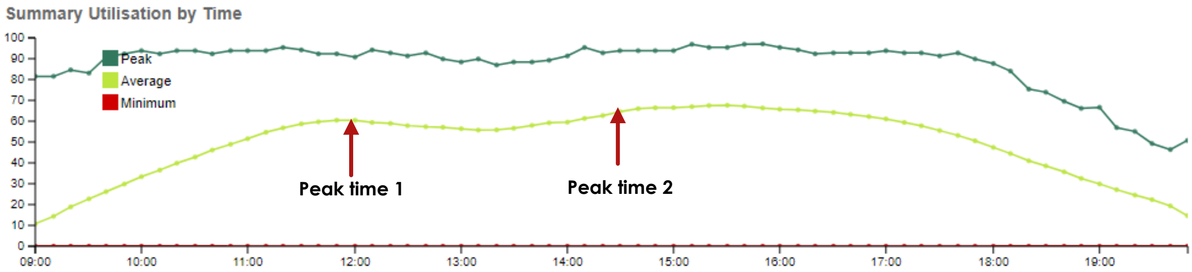
Appendix 3.5: Utilisation of the desks in the Bartlett Library in different months

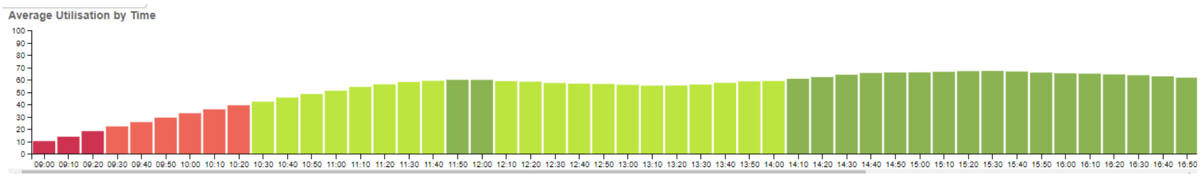


Appendix 3.6: Utilisation of the Bartlett Library in a week between 2018 and 2019



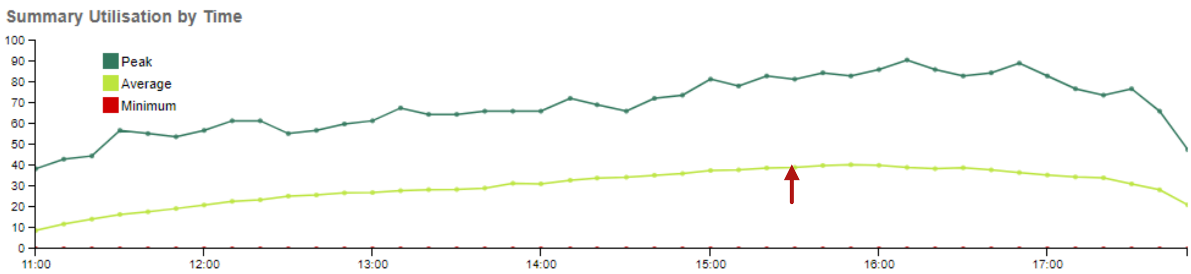
Appendix 3.7: Utilisation of the Bartlett Library by time on a weekday

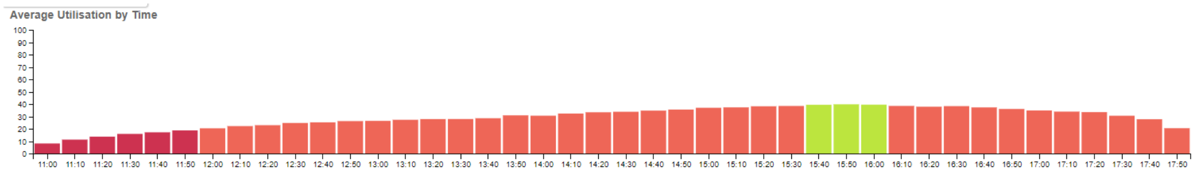




Total Spaces	Avg. Utilisation	No. of Spaces	Peak Utilisation	No. of Spaces	Peak Time
65	49.8%	32	97.1%	67	2018-11-29 15:50:00

Appendix 3.8: Utilisation of the Bartlett Library by time at a weekend





Total Spaces	Avg. Utilisation	No. of Spaces	Peak Utilisation	No. of Spaces	Peak Time
65	30.0%	19	90.8%	59	2018-04-21 16:10:00

Appendix 4: Utilization of the desks on a typical day

Appendix 4.1: Utilization of the desks in Room 1

	1	2	3	4	5	6	7	8	9	10	11	12
09:00-09:10	0.13	0.10	0.07	0.10	0.03	0.03	0.01	0.01	0.10	0.07	0.11	0.18
09:10-09:20	0.21	0.12	0.09	0.13	0.03	0.04	0.01	0.05	0.13	0.11	0.13	0.25
09:20-09:30	0.26	0.16	0.15	0.21	0.05	0.04	0.11	0.09	0.17	0.15	0.17	0.29
09:30-09:40	0.31	0.19	0.16	0.23	0.09	0.07	0.11	0.08	0.20	0.19	0.19	0.36
09:40-09:50	0.29	0.24	0.16	0.24	0.10	0.09	0.12	0.11	0.23	0.21	0.22	0.39
09:50-10:00	0.33	0.26	0.18	0.31	0.12	0.08	0.12	0.07	0.26	0.24	0.25	0.45
10:00-10:10	0.34	0.29	0.27	0.31	0.16	0.07	0.23	0.07	0.29	0.27	0.29	0.45
10:10-10:20	0.40	0.34	0.27	0.39	0.17	0.10	0.23	0.08	0.32	0.31	0.35	0.47
10:20-10:30	0.44	0.35	0.29	0.42	0.22	0.15	0.34	0.09	0.35	0.35	0.35	0.49
10:30-10:40	0.47	0.36	0.32	0.45	0.23	0.15	0.47	0.15	0.38	0.39	0.40	0.50
10:40-10:50	0.53	0.40	0.31	0.48	0.24	0.17	0.46	0.18	0.41	0.44	0.42	0.51
10:50-11:00	0.51	0.43	0.37	0.48	0.28	0.22	0.50	0.20	0.44	0.47	0.47	0.56
11:00-11:10	0.55	0.48	0.39	0.50	0.35	0.27	0.55	0.28	0.47	0.46	0.49	0.55
11:10-11:20	0.57	0.48	0.44	0.53	0.39	0.33	0.58	0.30	0.50	0.53	0.55	0.56
11:20-11:30	0.60	0.49	0.44	0.54	0.38	0.33	0.61	0.32	0.52	0.55	0.60	0.57
11:30-11:40	0.57	0.50	0.45	0.56	0.38	0.35	0.66	0.38	0.55	0.57	0.60	0.60
11:40-11:50	0.60	0.51	0.49	0.56	0.41	0.36	0.61	0.42	0.56	0.58	0.61	0.60
11:50-12:00	0.58	0.53	0.50	0.55	0.41	0.33	0.62	0.41	0.57	0.56	0.63	0.63
12:00-12:10	0.59	0.55	0.50	0.58	0.45	0.38	0.62	0.45	0.57	0.56	0.61	0.63
12:10-12:20	0.58	0.54	0.51	0.55	0.41	0.36	0.62	0.46	0.57	0.59	0.61	0.60
12:20-12:30	0.56	0.51	0.51	0.58	0.41	0.41	0.61	0.50	0.57	0.59	0.60	0.60
12:30-12:40	0.54	0.50	0.50	0.53	0.40	0.36	0.69	0.50	0.55	0.58	0.61	0.56
12:40-12:50	0.54	0.50	0.49	0.54	0.42	0.37	0.68	0.50	0.55	0.52	0.61	0.62
12:50-13:00	0.56	0.50	0.45	0.55	0.40	0.35	0.66	0.50	0.55	0.55	0.61	0.60
13:00-13:10	0.56	0.48	0.45	0.48	0.43	0.37	0.68	0.53	0.54	0.58	0.60	0.62
13:10-13:20	0.50	0.50	0.42	0.45	0.43	0.40	0.66	0.55	0.54	0.55	0.62	0.66
13:20-13:30	0.55	0.52	0.42	0.47	0.44	0.39	0.68	0.58	0.55	0.59	0.61	0.65
13:30-13:40	0.54	0.49	0.46	0.47	0.48	0.40	0.68	0.58	0.55	0.59	0.60	0.67
13:40-13:50	0.55	0.51	0.47	0.51	0.48	0.38	0.66	0.55	0.57	0.61	0.62	0.67
13:50-14:00	0.59	0.52	0.51	0.53	0.46	0.43	0.59	0.50	0.58	0.62	0.60	0.64
14:00-14:10	0.57	0.54	0.49	0.50	0.44	0.39	0.57	0.47	0.58	0.60	0.58	0.63
14:10-14:20	0.59	0.55	0.49	0.53	0.47	0.39	0.64	0.47	0.60	0.63	0.63	0.60
14:20-14:30	0.58	0.53	0.51	0.54	0.46	0.39	0.65	0.53	0.61	0.66	0.64	0.62
14:30-14:40	0.61	0.54	0.51	0.62	0.48	0.42	0.62	0.58	0.63	0.70	0.65	0.65
14:40-14:50	0.60	0.58	0.51	0.61	0.48	0.44	0.66	0.59	0.64	0.68	0.66	0.65
14:50-15:00	0.61	0.58	0.55	0.63	0.53	0.48	0.69	0.59	0.64	0.65	0.65	0.66
15:00-15:10	0.63	0.59	0.55	0.61	0.53	0.48	0.69	0.59	0.65	0.67	0.65	0.66
15:10-15:20	0.62	0.59	0.56	0.60	0.52	0.49	0.70	0.61	0.65	0.67	0.63	0.67
15:20-15:30	0.61	0.59	0.51	0.63	0.51	0.48	0.73	0.64	0.65	0.68	0.65	0.68
15:30-15:40	0.60	0.60	0.52	0.65	0.50	0.43	0.72	0.62	0.66	0.67	0.65	0.68
15:40-15:50	0.60	0.61	0.53	0.61	0.51	0.44	0.70	0.65	0.65	0.65	0.66	0.66
15:50-16:00	0.57	0.57	0.51	0.61	0.52	0.47	0.72	0.61	0.64	0.63	0.66	0.65
16:00-16:10	0.59	0.56	0.51	0.61	0.45	0.45	0.70	0.64	0.64	0.61	0.60	0.62
16:10-16:20	0.58	0.56	0.48	0.54	0.46	0.43	0.72	0.66	0.63	0.59	0.61	0.63
16:20-16:30	0.57	0.56	0.51	0.58	0.42	0.43	0.70	0.66	0.63	0.60	0.61	0.63
16:30-16:40	0.60	0.55	0.48	0.60	0.40	0.43	0.68	0.66	0.62	0.60	0.60	0.62
16:40-16:50	0.58	0.56	0.51	0.60	0.42	0.39	0.66	0.54	0.61	0.59	0.60	0.61
16:50-17:00	0.53	0.52	0.49	0.54	0.43	0.40	0.65	0.55	0.60	0.58	0.58	0.60
17:00-17:10	0.52	0.50	0.45	0.56	0.43	0.40	0.66	0.53	0.59	0.56	0.53	0.58
17:10-17:20	0.48	0.49	0.45	0.53	0.37	0.37	0.61	0.55	0.57	0.55	0.50	0.56
17:20-17:30	0.48	0.50	0.44	0.49	0.37	0.39	0.62	0.49	0.55	0.53	0.51	0.55
17:30-17:40	0.44	0.44	0.41	0.47	0.37	0.38	0.57	0.47	0.53	0.52	0.47	0.53
17:40-17:50	0.41	0.40	0.36	0.45	0.37	0.35	0.50	0.46	0.51	0.50	0.44	0.51
17:50-18:00	0.41	0.40	0.35	0.42	0.36	0.35	0.51	0.47	0.48	0.49	0.40	0.47
18:00-18:10	0.35	0.38	0.33	0.40	0.34	0.30	0.49	0.49	0.45	0.46	0.37	0.44
18:10-18:20	0.39	0.34	0.31	0.40	0.29	0.26	0.49	0.46	0.43	0.41	0.34	0.40
18:20-18:30	0.32	0.33	0.30	0.35	0.29	0.27	0.46	0.39	0.39	0.40	0.32	0.35
18:30-18:40	0.29	0.29	0.28	0.35	0.27	0.26	0.43	0.34	0.37	0.37	0.31	0.33
18:40-18:50	0.31	0.27	0.22	0.34	0.25	0.26	0.39	0.30	0.34	0.32	0.27	0.31
18:50-19:00	0.26	0.24	0.19	0.31	0.22	0.26	0.34	0.27	0.31	0.29	0.23	0.28
19:00-19:10	0.24	0.24	0.22	0.30	0.18	0.26	0.31	0.26	0.28	0.26	0.21	0.26
19:10-19:20	0.23	0.21	0.20	0.27	0.19	0.28	0.28	0.26	0.26	0.23	0.18	0.21
19:20-19:30	0.21	0.19	0.16	0.24	0.13	0.23	0.26	0.24	0.23	0.19	0.17	0.19
19:30-19:40	0.20	0.16	0.14	0.19	0.14	0.21	0.20	0.18	0.21	0.18	0.15	0.16
19:40-19:50	0.16	0.15	0.11	0.16	0.13	0.17	0.14	0.16	0.18	0.11	0.12	0.13
19:50-20:00	0.09	0.08	0.05	0.10	0.06	0.10	0.09	0.08	0.13	0.07	0.08	0.10

0-20% 20-40% 40-60% 60-80% 80-100%

Appendix 4.2: Utilization of the desks in Room 2

	13	14	15	16	17	18	19	20	21	22	23	24
09:00-09:10	0.21	0.05	0.15	0.08	0.19	0.07	0.24	0.11	0.15	0.10	0.32	0.13
09:10-09:20	0.32	0.10	0.20	0.09	0.26	0.09	0.30	0.14	0.23	0.14	0.47	0.18
09:20-09:30	0.43	0.11	0.30	0.13	0.35	0.15	0.40	0.17	0.28	0.18	0.56	0.20
09:30-09:40	0.51	0.19	0.37	0.17	0.42	0.23	0.49	0.22	0.39	0.22	0.65	0.23
09:40-09:50	0.58	0.25	0.47	0.26	0.49	0.25	0.54	0.23	0.45	0.25	0.69	0.27
09:50-10:00	0.64	0.30	0.54	0.31	0.57	0.30	0.62	0.28	0.53	0.29	0.73	0.34
10:00-10:10	0.66	0.37	0.62	0.40	0.60	0.39	0.66	0.34	0.62	0.33	0.76	0.34
10:10-10:20	0.68	0.44	0.68	0.47	0.66	0.44	0.70	0.40	0.66	0.36	0.77	0.41
10:20-10:30	0.71	0.53	0.70	0.50	0.67	0.50	0.76	0.48	0.73	0.39	0.81	0.48
10:30-10:40	0.73	0.57	0.74	0.55	0.76	0.55	0.79	0.55	0.76	0.42	0.84	0.53
10:40-10:50	0.74	0.65	0.74	0.57	0.78	0.61	0.80	0.59	0.77	0.45	0.84	0.57
10:50-11:00	0.77	0.66	0.76	0.60	0.79	0.65	0.80	0.62	0.80	0.48	0.85	0.60
11:00-11:10	0.78	0.71	0.76	0.65	0.81	0.68	0.81	0.66	0.78	0.51	0.83	0.65
11:10-11:20	0.79	0.74	0.79	0.66	0.80	0.71	0.82	0.71	0.81	0.54	0.86	0.66
11:20-11:30	0.79	0.76	0.78	0.71	0.81	0.72	0.82	0.69	0.79	0.56	0.87	0.70
11:30-11:40	0.81	0.75	0.77	0.70	0.80	0.71	0.84	0.74	0.81	0.58	0.85	0.69
11:40-11:50	0.79	0.76	0.77	0.72	0.81	0.74	0.82	0.68	0.82	0.59	0.85	0.72
11:50-12:00	0.76	0.74	0.75	0.70	0.79	0.73	0.81	0.73	0.79	0.60	0.82	0.72
12:00-12:10	0.77	0.71	0.74	0.69	0.79	0.71	0.76	0.68	0.80	0.60	0.77	0.69
12:10-12:20	0.74	0.69	0.71	0.68	0.74	0.68	0.74	0.67	0.75	0.59	0.74	0.66
12:20-12:30	0.72	0.68	0.67	0.63	0.74	0.67	0.72	0.68	0.73	0.59	0.75	0.65
12:30-12:40	0.68	0.66	0.66	0.67	0.74	0.67	0.70	0.68	0.71	0.58	0.73	0.63
12:40-12:50	0.68	0.63	0.65	0.67	0.68	0.66	0.71	0.67	0.73	0.57	0.71	0.64
12:50-13:00	0.70	0.65	0.64	0.67	0.71	0.65	0.68	0.67	0.69	0.57	0.70	0.66
13:00-13:10	0.65	0.61	0.61	0.65	0.63	0.60	0.68	0.67	0.70	0.56	0.70	0.64
13:10-13:20	0.65	0.58	0.62	0.64	0.60	0.59	0.64	0.61	0.66	0.55	0.66	0.65
13:20-13:30	0.61	0.58	0.61	0.66	0.55	0.58	0.64	0.59	0.66	0.56	0.63	0.63
13:30-13:40	0.65	0.58	0.63	0.60	0.58	0.61	0.64	0.58	0.66	0.56	0.65	0.65
13:40-13:50	0.69	0.63	0.67	0.61	0.63	0.61	0.65	0.61	0.68	0.58	0.62	0.64
13:50-14:00	0.68	0.65	0.71	0.63	0.64	0.63	0.65	0.66	0.66	0.59	0.65	0.64
14:00-14:10	0.71	0.69	0.69	0.65	0.59	0.63	0.68	0.68	0.68	0.59	0.68	0.65
14:10-14:20	0.72	0.68	0.74	0.71	0.61	0.64	0.70	0.68	0.68	0.61	0.67	0.70
14:20-14:30	0.76	0.69	0.73	0.72	0.64	0.66	0.71	0.70	0.71	0.62	0.70	0.71
14:30-14:40	0.77	0.74	0.73	0.73	0.69	0.70	0.71	0.71	0.74	0.64	0.71	0.72
14:40-14:50	0.80	0.74	0.74	0.74	0.73	0.72	0.76	0.72	0.80	0.66	0.76	0.74
14:50-15:00	0.79	0.74	0.79	0.74	0.76	0.71	0.78	0.73	0.83	0.66	0.75	0.71
15:00-15:10	0.80	0.73	0.78	0.73	0.75	0.69	0.79	0.70	0.79	0.66	0.79	0.74
15:10-15:20	0.83	0.73	0.79	0.73	0.76	0.72	0.80	0.71	0.80	0.67	0.78	0.73
15:20-15:30	0.81	0.76	0.77	0.73	0.79	0.74	0.81	0.75	0.81	0.67	0.81	0.73
15:30-15:40	0.80	0.74	0.78	0.73	0.79	0.72	0.79	0.76	0.79	0.67	0.81	0.71
15:40-15:50	0.80	0.73	0.77	0.74	0.77	0.74	0.80	0.77	0.80	0.67	0.81	0.73
15:50-16:00	0.79	0.74	0.75	0.73	0.72	0.74	0.80	0.78	0.79	0.66	0.82	0.72
16:00-16:10	0.78	0.73	0.74	0.74	0.73	0.75	0.77	0.74	0.77	0.65	0.82	0.76
16:10-16:20	0.73	0.72	0.74	0.73	0.73	0.75	0.81	0.74	0.76	0.65	0.83	0.77
16:20-16:30	0.77	0.70	0.73	0.71	0.70	0.72	0.79	0.74	0.77	0.64	0.81	0.75
16:30-16:40	0.75	0.71	0.73	0.73	0.73	0.73	0.78	0.72	0.77	0.64	0.78	0.74
16:40-16:50	0.75	0.71	0.73	0.72	0.73	0.73	0.78	0.74	0.75	0.63	0.77	0.72
16:50-17:00	0.69	0.72	0.74	0.72	0.71	0.71	0.78	0.71	0.74	0.62	0.80	0.71
17:00-17:10	0.71	0.70	0.72	0.72	0.69	0.71	0.75	0.71	0.71	0.61	0.77	0.73
17:10-17:20	0.72	0.70	0.67	0.70	0.69	0.69	0.75	0.69	0.73	0.59	0.76	0.68
17:20-17:30	0.65	0.68	0.67	0.68	0.69	0.67	0.71	0.68	0.73	0.57	0.75	0.68
17:30-17:40	0.67	0.65	0.64	0.65	0.71	0.65	0.69	0.66	0.68	0.55	0.74	0.65
17:40-17:50	0.63	0.62	0.61	0.60	0.67	0.63	0.66	0.65	0.64	0.53	0.72	0.60
17:50-18:00	0.60	0.57	0.60	0.57	0.63	0.61	0.65	0.63	0.62	0.50	0.70	0.60
18:00-18:10	0.58	0.53	0.54	0.52	0.60	0.54	0.63	0.60	0.56	0.47	0.65	0.53
18:10-18:20	0.53	0.49	0.51	0.45	0.56	0.52	0.60	0.53	0.54	0.44	0.60	0.50
18:20-18:30	0.52	0.45	0.48	0.44	0.53	0.49	0.60	0.50	0.50	0.41	0.53	0.46
18:30-18:40	0.48	0.40	0.49	0.42	0.52	0.45	0.54	0.45	0.45	0.38	0.48	0.45
18:40-18:50	0.46	0.38	0.45	0.39	0.45	0.41	0.50	0.44	0.41	0.35	0.47	0.43
18:50-19:00	0.44	0.37	0.41	0.34	0.40	0.35	0.47	0.39	0.38	0.32	0.41	0.39
19:00-19:10	0.45	0.31	0.40	0.32	0.39	0.32	0.45	0.36	0.32	0.30	0.40	0.34
19:10-19:20	0.42	0.30	0.38	0.29	0.36	0.31	0.43	0.33	0.29	0.27	0.34	0.32
19:20-19:30	0.39	0.28	0.35	0.25	0.35	0.29	0.36	0.27	0.28	0.24	0.32	0.30
19:30-19:40	0.35	0.25	0.34	0.22	0.31	0.27	0.35	0.29	0.26	0.22	0.31	0.31
19:40-19:50	0.33	0.19	0.31	0.21	0.30	0.24	0.30	0.23	0.23	0.19	0.27	0.26
19:50-20:00	0.26	0.15	0.23	0.16	0.23	0.17	0.25	0.21	0.22	0.15	0.19	0.18

	25	26	27	28	29	30	32	33	34	35
09:00-09:10	0.28	0.34	0.35	0.29	0.24	0.32	0.56	0.13	0.14	0.03
09:10-09:20	0.38	0.46	0.43	0.36	0.35	0.39	0.63	0.15	0.21	0.03
09:20-09:30	0.52	0.55	0.53	0.48	0.45	0.50	0.72	0.23	0.24	0.04
09:30-09:40	0.56	0.64	0.58	0.60	0.60	0.58	0.76	0.26	0.27	0.05
09:40-09:50	0.63	0.69	0.67	0.63	0.65	0.66	0.80	0.28	0.29	0.08
09:50-10:00	0.67	0.74	0.70	0.66	0.68	0.71	0.83	0.35	0.32	0.10
10:00-10:10	0.69	0.79	0.75	0.71	0.77	0.75	0.85	0.36	0.37	0.12
10:10-10:20	0.74	0.82	0.80	0.74	0.76	0.76	0.86	0.39	0.39	0.15
10:20-10:30	0.76	0.84	0.80	0.77	0.79	0.80	0.85	0.41	0.40	0.15
10:30-10:40	0.75	0.83	0.78	0.74	0.80	0.79	0.86	0.43	0.41	0.19
10:40-10:50	0.77	0.83	0.82	0.77	0.82	0.81	0.86	0.48	0.48	0.23
10:50-11:00	0.80	0.83	0.77	0.81	0.82	0.79	0.84	0.48	0.51	0.26
11:00-11:10	0.79	0.85	0.80	0.81	0.83	0.80	0.86	0.53	0.55	0.29
11:10-11:20	0.81	0.84	0.81	0.81	0.83	0.81	0.87	0.56	0.56	0.34
11:20-11:30	0.81	0.86	0.82	0.83	0.82	0.78	0.84	0.55	0.60	0.34
11:30-11:40	0.81	0.87	0.83	0.83	0.81	0.79	0.84	0.58	0.61	0.32
11:40-11:50	0.81	0.87	0.79	0.82	0.80	0.81	0.85	0.58	0.63	0.34
11:50-12:00	0.80	0.86	0.77	0.82	0.78	0.80	0.85	0.60	0.65	0.32
12:00-12:10	0.77	0.84	0.78	0.79	0.76	0.76	0.84	0.57	0.65	0.37
12:10-12:20	0.73	0.80	0.75	0.76	0.71	0.77	0.81	0.58	0.66	0.40
12:20-12:30	0.74	0.76	0.74	0.74	0.73	0.77	0.75	0.59	0.65	0.37
12:30-12:40	0.69	0.73	0.68	0.72	0.73	0.73	0.73	0.61	0.64	0.42
12:40-12:50	0.68	0.71	0.70	0.68	0.71	0.74	0.71	0.62	0.63	0.39
12:50-13:00	0.65	0.67	0.65	0.69	0.69	0.71	0.70	0.58	0.65	0.42
13:00-13:10	0.64	0.69	0.64	0.69	0.71	0.71	0.67	0.56	0.67	0.39
13:10-13:20	0.66	0.62	0.61	0.70	0.68	0.69	0.62	0.60	0.66	0.37
13:20-13:30	0.68	0.58	0.64	0.72	0.65	0.69	0.61	0.59	0.67	0.42
13:30-13:40	0.68	0.59	0.68	0.72	0.64	0.71	0.61	0.61	0.68	0.45
13:40-13:50	0.69	0.61	0.66	0.72	0.69	0.73	0.62	0.61	0.66	0.42
13:50-14:00	0.71	0.68	0.69	0.74	0.72	0.71	0.66	0.59	0.69	0.43
14:00-14:10	0.71	0.72	0.71	0.73	0.71	0.73	0.68	0.57	0.63	0.39
14:10-14:20	0.75	0.75	0.72	0.71	0.73	0.75	0.71	0.56	0.64	0.44
14:20-14:30	0.75	0.77	0.74	0.76	0.73	0.76	0.74	0.60	0.69	0.45
14:30-14:40	0.76	0.82	0.77	0.77	0.76	0.79	0.75	0.64	0.72	0.52
14:40-14:50	0.82	0.81	0.78	0.80	0.79	0.80	0.77	0.62	0.72	0.50
14:50-15:00	0.82	0.81	0.79	0.79	0.79	0.79	0.78	0.65	0.72	0.51
15:00-15:10	0.83	0.84	0.80	0.81	0.81	0.81	0.77	0.65	0.68	0.49
15:10-15:20	0.83	0.83	0.79	0.81	0.83	0.84	0.77	0.64	0.72	0.51
15:20-15:30	0.83	0.85	0.82	0.81	0.81	0.82	0.79	0.62	0.75	0.51
15:30-15:40	0.84	0.85	0.79	0.82	0.85	0.82	0.79	0.63	0.76	0.52
15:40-15:50	0.82	0.84	0.79	0.80	0.82	0.79	0.82	0.64	0.71	0.52
15:50-16:00	0.80	0.84	0.80	0.79	0.78	0.79	0.83	0.64	0.69	0.47
16:00-16:10	0.81	0.81	0.79	0.79	0.81	0.81	0.82	0.65	0.74	0.50
16:10-16:20	0.80	0.83	0.75	0.74	0.82	0.84	0.83	0.65	0.73	0.47
16:20-16:30	0.80	0.83	0.78	0.79	0.82	0.82	0.82	0.64	0.71	0.45
16:30-16:40	0.79	0.81	0.79	0.77	0.81	0.81	0.82	0.63	0.71	0.45
16:40-16:50	0.81	0.78	0.77	0.76	0.81	0.81	0.82	0.61	0.71	0.45
16:50-17:00	0.78	0.77	0.80	0.75	0.79	0.79	0.77	0.60	0.69	0.43
17:00-17:10	0.79	0.76	0.79	0.80	0.80	0.78	0.78	0.60	0.69	0.43
17:10-17:20	0.78	0.77	0.80	0.76	0.76	0.76	0.78	0.56	0.68	0.43
17:20-17:30	0.75	0.71	0.78	0.77	0.74	0.71	0.77	0.56	0.68	0.38
17:30-17:40	0.75	0.71	0.69	0.74	0.76	0.73	0.77	0.53	0.65	0.35
17:40-17:50	0.71	0.71	0.73	0.72	0.74	0.71	0.75	0.55	0.63	0.34
17:50-18:00	0.67	0.68	0.69	0.66	0.71	0.66	0.69	0.56	0.63	0.34
18:00-18:10	0.63	0.65	0.69	0.65	0.69	0.65	0.69	0.52	0.60	0.34
18:10-18:20	0.60	0.65	0.66	0.62	0.65	0.61	0.65	0.52	0.58	0.31
18:20-18:30	0.60	0.57	0.60	0.60	0.60	0.60	0.59	0.45	0.51	0.25
18:30-18:40	0.60	0.55	0.58	0.55	0.60	0.57	0.54	0.45	0.48	0.25
18:40-18:50	0.54	0.55	0.54	0.55	0.58	0.56	0.50	0.40	0.46	0.22
18:50-19:00	0.49	0.51	0.49	0.51	0.57	0.51	0.46	0.35	0.45	0.23
19:00-19:10	0.46	0.48	0.48	0.47	0.55	0.45	0.42	0.37	0.42	0.21
19:10-19:20	0.40	0.43	0.45	0.43	0.50	0.40	0.38	0.33	0.44	0.19
19:20-19:30	0.37	0.37	0.42	0.43	0.44	0.39	0.35	0.31	0.37	0.19
19:30-19:40	0.35	0.36	0.40	0.41	0.39	0.34	0.34	0.32	0.39	0.17
19:40-19:50	0.32	0.28	0.35	0.35	0.30	0.27	0.27	0.30	0.37	0.20
19:50-20:00	0.22	0.18	0.23	0.24	0.19	0.21	0.22	0.24	0.29	0.16

0-20% 20-40% 40-60% 60-80% 80-100%

Appendix 4.3: Utilization of the desks in Room 3

	36	37	38	39	40	41	42	43	44	45	46	47
09:00-09:10	0.02	0.06	0.03	0.13	0.02	0.02	0.03	0.04	0.05	0.05	0.02	0.08
09:10-09:20	0.03	0.08	0.05	0.18	0.03	0.03	0.03	0.06	0.07	0.09	0.02	0.12
09:20-09:30	0.07	0.13	0.09	0.23	0.04	0.06	0.07	0.08	0.10	0.10	0.02	0.14
09:30-09:40	0.11	0.17	0.11	0.28	0.05	0.08	0.09	0.10	0.12	0.13	0.03	0.18
09:40-09:50	0.16	0.23	0.15	0.35	0.08	0.11	0.11	0.15	0.15	0.15	0.05	0.21
09:50-10:00	0.19	0.26	0.18	0.40	0.10	0.14	0.14	0.18	0.17	0.19	0.06	0.26
10:00-10:10	0.25	0.33	0.19	0.45	0.14	0.16	0.17	0.19	0.19	0.21	0.07	0.30
10:10-10:20	0.27	0.35	0.22	0.49	0.14	0.19	0.18	0.20	0.25	0.22	0.08	0.32
10:20-10:30	0.32	0.40	0.24	0.54	0.18	0.24	0.23	0.26	0.29	0.27	0.09	0.37
10:30-10:40	0.34	0.44	0.31	0.58	0.19	0.27	0.25	0.30	0.32	0.32	0.10	0.40
10:40-10:50	0.38	0.47	0.36	0.59	0.25	0.32	0.32	0.35	0.39	0.35	0.11	0.46
10:50-11:00	0.42	0.52	0.38	0.62	0.28	0.37	0.34	0.36	0.44	0.42	0.12	0.49
11:00-11:10	0.48	0.58	0.42	0.61	0.31	0.42	0.39	0.41	0.45	0.43	0.11	0.53
11:10-11:20	0.51	0.61	0.48	0.62	0.37	0.46	0.45	0.49	0.47	0.50	0.15	0.56
11:20-11:30	0.53	0.64	0.51	0.67	0.39	0.50	0.50	0.51	0.53	0.55	0.17	0.62
11:30-11:40	0.56	0.65	0.53	0.67	0.44	0.54	0.54	0.55	0.60	0.59	0.16	0.61
11:40-11:50	0.58	0.66	0.54	0.69	0.47	0.56	0.56	0.56	0.59	0.62	0.17	0.62
11:50-12:00	0.60	0.69	0.57	0.69	0.47	0.55	0.56	0.60	0.62	0.65	0.18	0.65
12:00-12:10	0.62	0.71	0.54	0.68	0.50	0.57	0.56	0.60	0.62	0.63	0.18	0.63
12:10-12:20	0.60	0.67	0.54	0.66	0.52	0.56	0.57	0.59	0.61	0.61	0.18	0.63
12:20-12:30	0.60	0.64	0.53	0.65	0.51	0.55	0.57	0.61	0.60	0.62	0.18	0.60
12:30-12:40	0.58	0.66	0.51	0.60	0.50	0.52	0.56	0.62	0.63	0.65	0.17	0.61
12:40-12:50	0.58	0.65	0.54	0.60	0.49	0.52	0.54	0.63	0.60	0.60	0.16	0.60
12:50-13:00	0.55	0.63	0.55	0.62	0.52	0.52	0.53	0.63	0.60	0.60	0.18	0.59
13:00-13:10	0.55	0.64	0.52	0.58	0.50	0.53	0.54	0.61	0.55	0.64	0.18	0.60
13:10-13:20	0.55	0.61	0.55	0.63	0.52	0.52	0.62	0.61	0.59	0.65	0.19	0.61
13:20-13:30	0.57	0.61	0.56	0.66	0.50	0.55	0.64	0.62	0.56	0.61	0.18	0.65
13:30-13:40	0.56	0.63	0.56	0.65	0.51	0.58	0.60	0.59	0.60	0.60	0.17	0.65
13:40-13:50	0.59	0.66	0.58	0.66	0.55	0.60	0.62	0.63	0.60	0.64	0.18	0.68
13:50-14:00	0.56	0.65	0.59	0.61	0.56	0.58	0.64	0.61	0.62	0.66	0.19	0.67
14:00-14:10	0.59	0.68	0.63	0.66	0.57	0.57	0.64	0.61	0.64	0.68	0.19	0.69
14:10-14:20	0.59	0.70	0.66	0.68	0.62	0.60	0.65	0.62	0.67	0.67	0.21	0.69
14:20-14:30	0.63	0.69	0.67	0.70	0.61	0.63	0.63	0.64	0.68	0.68	0.22	0.71
14:30-14:40	0.69	0.71	0.65	0.68	0.63	0.66	0.65	0.66	0.68	0.68	0.23	0.72
14:40-14:50	0.70	0.73	0.66	0.68	0.66	0.67	0.66	0.69	0.72	0.73	0.21	0.71
14:50-15:00	0.71	0.73	0.68	0.69	0.65	0.65	0.66	0.68	0.72	0.75	0.20	0.71
15:00-15:10	0.70	0.72	0.69	0.68	0.67	0.65	0.66	0.69	0.68	0.71	0.21	0.71
15:10-15:20	0.70	0.75	0.69	0.69	0.65	0.67	0.66	0.68	0.68	0.71	0.21	0.74
15:20-15:30	0.69	0.77	0.70	0.72	0.68	0.66	0.66	0.68	0.68	0.71	0.20	0.78
15:30-15:40	0.70	0.77	0.69	0.73	0.69	0.70	0.66	0.69	0.72	0.71	0.20	0.73
15:40-15:50	0.71	0.77	0.68	0.73	0.62	0.71	0.66	0.69	0.71	0.69	0.20	0.73
15:50-16:00	0.70	0.74	0.67	0.69	0.64	0.70	0.65	0.68	0.69	0.70	0.19	0.72
16:00-16:10	0.66	0.76	0.68	0.73	0.63	0.73	0.68	0.65	0.70	0.66	0.19	0.71
16:10-16:20	0.67	0.75	0.67	0.73	0.61	0.71	0.68	0.68	0.70	0.70	0.20	0.72
16:20-16:30	0.68	0.72	0.64	0.71	0.60	0.67	0.66	0.69	0.69	0.72	0.19	0.68
16:30-16:40	0.66	0.72	0.61	0.71	0.60	0.66	0.68	0.68	0.67	0.71	0.19	0.66
16:40-16:50	0.61	0.69	0.63	0.68	0.60	0.63	0.68	0.66	0.65	0.69	0.20	0.64
16:50-17:00	0.63	0.66	0.60	0.66	0.62	0.63	0.66	0.61	0.65	0.68	0.19	0.66
17:00-17:10	0.61	0.65	0.62	0.69	0.58	0.62	0.61	0.62	0.61	0.65	0.19	0.63
17:10-17:20	0.61	0.64	0.60	0.67	0.58	0.61	0.56	0.60	0.59	0.65	0.19	0.63
17:20-17:30	0.59	0.61	0.56	0.64	0.56	0.59	0.54	0.58	0.58	0.62	0.17	0.61
17:30-17:40	0.53	0.59	0.51	0.59	0.51	0.57	0.53	0.54	0.55	0.58	0.18	0.56
17:40-17:50	0.51	0.58	0.47	0.57	0.51	0.57	0.51	0.50	0.52	0.56	0.16	0.56
17:50-18:00	0.49	0.53	0.45	0.53	0.45	0.53	0.46	0.47	0.48	0.56	0.15	0.54
18:00-18:10	0.45	0.51	0.40	0.46	0.41	0.50	0.43	0.40	0.45	0.48	0.13	0.49
18:10-18:20	0.44	0.48	0.39	0.43	0.39	0.45	0.40	0.38	0.43	0.43	0.13	0.47
18:20-18:30	0.36	0.43	0.34	0.38	0.35	0.37	0.40	0.37	0.37	0.40	0.12	0.42
18:30-18:40	0.34	0.38	0.32	0.35	0.33	0.39	0.37	0.32	0.34	0.35	0.09	0.40
18:40-18:50	0.32	0.35	0.27	0.31	0.31	0.35	0.30	0.30	0.31	0.33	0.08	0.35
18:50-19:00	0.28	0.34	0.24	0.31	0.31	0.32	0.29	0.26	0.29	0.29	0.07	0.32
19:00-19:10	0.25	0.29	0.21	0.25	0.26	0.29	0.27	0.23	0.30	0.23	0.05	0.27
19:10-19:20	0.22	0.27	0.17	0.23	0.21	0.24	0.24	0.19	0.28	0.20	0.05	0.24
19:20-19:30	0.19	0.26	0.15	0.21	0.21	0.21	0.21	0.17	0.26	0.18	0.05	0.22
19:30-19:40	0.18	0.24	0.12	0.18	0.18	0.18	0.18	0.14	0.24	0.16	0.05	0.15
19:40-19:50	0.16	0.20	0.08	0.15	0.18	0.15	0.15	0.15	0.19	0.15	0.04	0.13
19:50-20:00	0.12	0.18	0.07	0.12	0.18	0.13	0.14	0.13	0.14	0.11	0.04	0.10

	48	49	50	51	52	53	54	55	56	57	58	59
09:00-09:10	0.04	0.03	0.03	0.03	0.05	0.04	0.04	0.07	0.06	0.06	0.05	0.08
09:10-09:20	0.07	0.05	0.05	0.06	0.05	0.05	0.06	0.08	0.09	0.10	0.08	0.14
09:20-09:30	0.10	0.09	0.06	0.13	0.08	0.11	0.08	0.14	0.13	0.11	0.09	0.18
09:30-09:40	0.11	0.11	0.06	0.16	0.13	0.15	0.10	0.18	0.17	0.15	0.12	0.24
09:40-09:50	0.14	0.14	0.08	0.20	0.14	0.17	0.11	0.24	0.19	0.15	0.16	0.28
09:50-10:00	0.18	0.17	0.10	0.24	0.17	0.22	0.13	0.28	0.23	0.18	0.18	0.32
10:00-10:10	0.19	0.21	0.12	0.27	0.20	0.24	0.16	0.29	0.25	0.21	0.22	0.38
10:10-10:20	0.19	0.23	0.12	0.31	0.24	0.28	0.19	0.31	0.30	0.26	0.22	0.42
10:20-10:30	0.24	0.26	0.15	0.33	0.27	0.31	0.21	0.34	0.32	0.27	0.27	0.42
10:30-10:40	0.28	0.29	0.18	0.37	0.31	0.35	0.23	0.35	0.35	0.33	0.30	0.46
10:40-10:50	0.35	0.34	0.21	0.41	0.34	0.39	0.27	0.39	0.38	0.37	0.34	0.51
10:50-11:00	0.40	0.38	0.23	0.45	0.36	0.42	0.28	0.43	0.43	0.43	0.38	0.55
11:00-11:10	0.41	0.43	0.27	0.53	0.41	0.45	0.32	0.43	0.50	0.45	0.41	0.56
11:10-11:20	0.46	0.50	0.34	0.55	0.42	0.48	0.40	0.50	0.52	0.47	0.44	0.58
11:20-11:30	0.52	0.52	0.37	0.58	0.45	0.52	0.43	0.53	0.55	0.53	0.47	0.61
11:30-11:40	0.55	0.55	0.38	0.61	0.51	0.57	0.46	0.57	0.62	0.57	0.50	0.64
11:40-11:50	0.55	0.58	0.42	0.62	0.49	0.58	0.46	0.58	0.62	0.59	0.50	0.66
11:50-12:00	0.58	0.60	0.45	0.66	0.52	0.61	0.52	0.58	0.61	0.62	0.52	0.68
12:00-12:10	0.58	0.63	0.45	0.66	0.55	0.60	0.52	0.59	0.63	0.61	0.52	0.67
12:10-12:20	0.58	0.60	0.45	0.62	0.54	0.60	0.54	0.58	0.62	0.60	0.50	0.64
12:20-12:30	0.57	0.59	0.44	0.60	0.52	0.63	0.54	0.56	0.63	0.60	0.48	0.66
12:30-12:40	0.58	0.61	0.44	0.59	0.52	0.59	0.52	0.60	0.63	0.60	0.47	0.59
12:40-12:50	0.56	0.61	0.48	0.59	0.52	0.60	0.51	0.56	0.59	0.61	0.48	0.58
12:50-13:00	0.57	0.58	0.50	0.60	0.52	0.61	0.52	0.58	0.63	0.63	0.52	0.60
13:00-13:10	0.55	0.59	0.48	0.60	0.50	0.58	0.49	0.58	0.58	0.66	0.53	0.61
13:10-13:20	0.56	0.58	0.50	0.59	0.52	0.54	0.50	0.58	0.56	0.63	0.55	0.60
13:20-13:30	0.55	0.58	0.48	0.56	0.52	0.55	0.50	0.58	0.56	0.60	0.59	0.59
13:30-13:40	0.58	0.61	0.48	0.60	0.53	0.55	0.52	0.61	0.56	0.59	0.59	0.58
13:40-13:50	0.58	0.60	0.50	0.60	0.57	0.56	0.55	0.63	0.61	0.60	0.59	0.60
13:50-14:00	0.58	0.62	0.52	0.61	0.60	0.63	0.59	0.63	0.66	0.61	0.61	0.60
14:00-14:10	0.56	0.64	0.52	0.63	0.58	0.63	0.56	0.61	0.62	0.62	0.62	0.58
14:10-14:20	0.58	0.66	0.52	0.64	0.61	0.65	0.56	0.61	0.66	0.61	0.66	0.62
14:20-14:30	0.59	0.68	0.55	0.67	0.64	0.68	0.55	0.62	0.64	0.63	0.64	0.66
14:30-14:40	0.62	0.71	0.59	0.72	0.65	0.71	0.58	0.66	0.64	0.63	0.65	0.66
14:40-14:50	0.64	0.72	0.61	0.73	0.67	0.70	0.59	0.65	0.67	0.65	0.62	0.69
14:50-15:00	0.65	0.72	0.60	0.74	0.63	0.74	0.60	0.62	0.68	0.65	0.62	0.68
15:00-15:10	0.68	0.69	0.61	0.73	0.65	0.71	0.64	0.64	0.74	0.66	0.64	0.68
15:10-15:20	0.67	0.72	0.62	0.73	0.63	0.71	0.67	0.63	0.69	0.65	0.64	0.67
15:20-15:30	0.67	0.70	0.63	0.71	0.65	0.72	0.66	0.64	0.71	0.65	0.67	0.66
15:30-15:40	0.70	0.70	0.60	0.74	0.67	0.73	0.67	0.67	0.72	0.67	0.66	0.67
15:40-15:50	0.71	0.73	0.59	0.71	0.69	0.69	0.68	0.66	0.71	0.65	0.64	0.66
15:50-16:00	0.70	0.70	0.59	0.71	0.65	0.70	0.68	0.64	0.69	0.69	0.62	0.66
16:00-16:10	0.70	0.71	0.60	0.70	0.62	0.68	0.66	0.61	0.67	0.67	0.61	0.65
16:10-16:20	0.70	0.70	0.60	0.71	0.65	0.66	0.66	0.62	0.67	0.67	0.61	0.65
16:20-16:30	0.67	0.68	0.56	0.71	0.63	0.65	0.64	0.60	0.69	0.66	0.58	0.65
16:30-16:40	0.66	0.65	0.56	0.69	0.64	0.65	0.63	0.61	0.65	0.63	0.60	0.65
16:40-16:50	0.67	0.66	0.54	0.66	0.63	0.65	0.63	0.61	0.67	0.62	0.61	0.62
16:50-17:00	0.63	0.65	0.56	0.64	0.61	0.63	0.63	0.60	0.65	0.60	0.62	0.62
17:00-17:10	0.61	0.64	0.53	0.62	0.60	0.62	0.63	0.58	0.61	0.60	0.63	0.62
17:10-17:20	0.60	0.60	0.49	0.62	0.61	0.60	0.58	0.56	0.59	0.56	0.59	0.61
17:20-17:30	0.61	0.61	0.51	0.61	0.61	0.58	0.57	0.52	0.56	0.53	0.56	0.60
17:30-17:40	0.58	0.57	0.47	0.56	0.56	0.57	0.54	0.53	0.56	0.55	0.55	0.58
17:40-17:50	0.53	0.51	0.40	0.55	0.52	0.55	0.53	0.48	0.55	0.50	0.52	0.58
17:50-18:00	0.52	0.49	0.40	0.49	0.52	0.52	0.52	0.45	0.48	0.48	0.47	0.53
18:00-18:10	0.49	0.47	0.38	0.48	0.47	0.49	0.50	0.42	0.45	0.44	0.43	0.49
18:10-18:20	0.46	0.44	0.35	0.45	0.41	0.47	0.45	0.40	0.44	0.41	0.41	0.47
18:20-18:30	0.41	0.41	0.30	0.38	0.40	0.44	0.40	0.39	0.37	0.37	0.38	0.45
18:30-18:40	0.40	0.34	0.27	0.35	0.37	0.41	0.37	0.33	0.39	0.35	0.37	0.40
18:40-18:50	0.34	0.34	0.24	0.30	0.36	0.38	0.35	0.30	0.37	0.34	0.33	0.37
18:50-19:00	0.32	0.32	0.22	0.26	0.33	0.35	0.30	0.26	0.33	0.29	0.30	0.34
19:00-19:10	0.31	0.30	0.20	0.24	0.29	0.32	0.31	0.24	0.30	0.26	0.27	0.29
19:10-19:20	0.28	0.25	0.19	0.22	0.25	0.31	0.25	0.23	0.26	0.26	0.23	0.23
19:20-19:30	0.24	0.24	0.16	0.20	0.25	0.26	0.23	0.19	0.24	0.22	0.19	0.20
19:30-19:40	0.20	0.21	0.15	0.17	0.21	0.24	0.20	0.15	0.19	0.17	0.18	0.18
19:40-19:50	0.16	0.19	0.12	0.16	0.20	0.19	0.16	0.14	0.19	0.15	0.17	0.13
19:50-20:00	0.15	0.14	0.08	0.12	0.14	0.15	0.12	0.10	0.15	0.12	0.11	0.09

	60	61	62	63	64	65	66	67
09:00-09:10	0.02	0.03	0.04	0.08	0.04	0.05	0.07	0.08
09:10-09:20	0.02	0.04	0.05	0.10	0.05	0.05	0.07	0.12
09:20-09:30	0.03	0.04	0.06	0.10	0.06	0.06	0.07	0.15
09:30-09:40	0.04	0.06	0.08	0.10	0.06	0.07	0.07	0.19
09:40-09:50	0.05	0.08	0.10	0.11	0.11	0.08	0.09	0.23
09:50-10:00	0.06	0.10	0.10	0.14	0.13	0.11	0.11	0.28
10:00-10:10	0.07	0.11	0.12	0.18	0.21	0.16	0.10	0.31
10:10-10:20	0.10	0.13	0.13	0.21	0.25	0.20	0.12	0.34
10:20-10:30	0.11	0.15	0.16	0.25	0.33	0.23	0.13	0.38
10:30-10:40	0.15	0.18	0.17	0.26	0.39	0.25	0.14	0.42
10:40-10:50	0.17	0.21	0.20	0.28	0.43	0.29	0.16	0.45
10:50-11:00	0.24	0.26	0.22	0.31	0.50	0.32	0.18	0.49
11:00-11:10	0.25	0.26	0.25	0.34	0.56	0.39	0.19	0.53
11:10-11:20	0.30	0.31	0.27	0.36	0.61	0.42	0.22	0.53
11:20-11:30	0.30	0.33	0.33	0.42	0.63	0.46	0.24	0.58
11:30-11:40	0.37	0.37	0.34	0.45	0.65	0.49	0.25	0.62
11:40-11:50	0.35	0.40	0.38	0.50	0.68	0.51	0.24	0.62
11:50-12:00	0.37	0.44	0.43	0.53	0.68	0.54	0.26	0.64
12:00-12:10	0.42	0.46	0.45	0.56	0.68	0.53	0.27	0.63
12:10-12:20	0.43	0.49	0.50	0.55	0.69	0.54	0.25	0.63
12:20-12:30	0.43	0.53	0.49	0.58	0.66	0.56	0.26	0.64
12:30-12:40	0.44	0.51	0.49	0.56	0.66	0.53	0.27	0.63
12:40-12:50	0.42	0.51	0.48	0.55	0.65	0.53	0.26	0.61
12:50-13:00	0.39	0.51	0.50	0.55	0.62	0.54	0.27	0.59
13:00-13:10	0.40	0.50	0.52	0.53	0.60	0.55	0.29	0.59
13:10-13:20	0.42	0.46	0.50	0.49	0.56	0.54	0.25	0.55
13:20-13:30	0.42	0.48	0.48	0.50	0.57	0.57	0.26	0.56
13:30-13:40	0.44	0.50	0.47	0.50	0.59	0.57	0.27	0.58
13:40-13:50	0.46	0.51	0.48	0.53	0.61	0.60	0.28	0.60
13:50-14:00	0.51	0.51	0.51	0.54	0.64	0.62	0.29	0.60
14:00-14:10	0.51	0.52	0.53	0.59	0.62	0.65	0.31	0.62
14:10-14:20	0.54	0.55	0.54	0.59	0.61	0.67	0.31	0.69
14:20-14:30	0.57	0.57	0.53	0.60	0.63	0.67	0.32	0.69
14:30-14:40	0.56	0.58	0.57	0.61	0.63	0.71	0.32	0.69
14:40-14:50	0.59	0.60	0.60	0.61	0.66	0.69	0.33	0.73
14:50-15:00	0.61	0.58	0.62	0.62	0.65	0.69	0.31	0.70
15:00-15:10	0.58	0.58	0.62	0.64	0.65	0.70	0.31	0.71
15:10-15:20	0.59	0.60	0.62	0.64	0.66	0.71	0.34	0.73
15:20-15:30	0.60	0.59	0.65	0.65	0.66	0.69	0.34	0.69
15:30-15:40	0.61	0.59	0.64	0.65	0.65	0.69	0.34	0.71
15:40-15:50	0.59	0.60	0.65	0.64	0.65	0.70	0.33	0.70
15:50-16:00	0.60	0.56	0.63	0.62	0.71	0.69	0.33	0.70
16:00-16:10	0.55	0.56	0.62	0.62	0.67	0.66	0.31	0.71
16:10-16:20	0.56	0.56	0.60	0.63	0.68	0.68	0.31	0.67
16:20-16:30	0.56	0.58	0.62	0.62	0.67	0.65	0.30	0.69
16:30-16:40	0.56	0.57	0.61	0.62	0.69	0.65	0.30	0.66
16:40-16:50	0.55	0.55	0.58	0.61	0.66	0.64	0.32	0.63
16:50-17:00	0.50	0.53	0.59	0.61	0.61	0.63	0.31	0.61
17:00-17:10	0.50	0.54	0.57	0.60	0.60	0.60	0.27	0.57
17:10-17:20	0.48	0.55	0.55	0.57	0.56	0.57	0.28	0.56
17:20-17:30	0.47	0.52	0.52	0.56	0.56	0.56	0.27	0.53
17:30-17:40	0.47	0.50	0.50	0.54	0.54	0.53	0.25	0.52
17:40-17:50	0.44	0.48	0.47	0.52	0.52	0.51	0.23	0.52
17:50-18:00	0.41	0.45	0.44	0.49	0.48	0.49	0.22	0.49
18:00-18:10	0.40	0.42	0.41	0.47	0.41	0.47	0.22	0.47
18:10-18:20	0.38	0.40	0.39	0.44	0.39	0.42	0.18	0.44
18:20-18:30	0.32	0.35	0.35	0.40	0.34	0.43	0.20	0.38
18:30-18:40	0.31	0.32	0.34	0.38	0.32	0.39	0.19	0.36
18:40-18:50	0.29	0.32	0.32	0.35	0.30	0.35	0.17	0.32
18:50-19:00	0.25	0.26	0.29	0.32	0.27	0.32	0.16	0.27
19:00-19:10	0.23	0.24	0.27	0.29	0.24	0.29	0.13	0.23
19:10-19:20	0.19	0.20	0.24	0.26	0.22	0.23	0.11	0.21
19:20-19:30	0.14	0.18	0.23	0.24	0.20	0.21	0.09	0.19
19:30-19:40	0.16	0.16	0.18	0.23	0.16	0.16	0.07	0.18
19:40-19:50	0.13	0.14	0.16	0.18	0.11	0.13	0.08	0.16
19:50-20:00	0.10	0.10	0.11	0.12	0.09	0.11	0.09	0.16

0-20% 20-40% 40-60% 60-80% 80-100%

Appendix 5: The questionnaire used for the research project in Chapter 6

Bartlett School Environment, Energy and Resources
Upper Woburn Place WC1H ONN London

UCL

I'm a PhD student under supervision of Dr. Hector Altamirano and Dr. Jemima Unwin. I would like to invite you to participate in my research project. I'm looking for students coming from different countries and regions, correspondingly, different climate conditions.

If you decide to participate, I will ask you to fill this brief questionnaire which should take around 5-10 minutes. Thank you for taking the time to consider participating in this study. Please do not hesitate to send me questions you may have.

❑ I agree that the research project has been explained to me and I agree to take part in this study.

Gizem Izmir Tunahan
Email: gizem.izmir.tunahan.17@ucl.ac.uk

1. Gender

❑ Male ❑ Female ❑ Other: ______ ❑ Prefer not to say

2. Age

❑ <20 ❑ 20-24 ❑ 25-29 ❑ 30-34 ❑ >35

3. Approximately how long have you been in or around London?

____years ____months ❑ I am a visitor: ____days

4. How would you describe your ethnicity?
(Please, **choose** one section and then, **select** one option to best describe your ethnic group or background)

❑ **White:** British, English, Northern Irish, Scottish or Welsh, Irish, Gypsy or Irish traveller, Any other White ethnic group: __________
❑ **Mixed/Multiple ethnic groups:** White and Black Caribbean, White and Black African, White and Asian, Any other Mixed or Multiple ethnic group: __________
❑ **Asian/Asian British:** Indian, Pakistani, Bangladeshi, Chinese, Any other Asian: __________
❑ **Black/African/Caribbean/Black British:** Caribbean, African, Any other Black / African / Caribbean: __________
❑ **Other ethnic groups:** Arab, Any other ethnic group: __________

5. How do you describe your cultural background? ______________________
(it depends on your own definition of culture as a part of your life style)

6. Please, fill out the blanks below (Please, indicate **the most specific place**)

	COUNTRY		CITY	
Where were you **born**?				
Where are your **parents** from?	**Mother**	**Father**	**Mother**	**Father**
Where did you live for **most of** your life?				
	How long:			
Where did you live **in the last year** before coming to London? (If you lived in **multiple places**, please fill all blanks with specific time durations) (Please indicate initially, most current one)				
	How long:			
	How long:			

7. How many days do you have a regular work schedule?
(regular work days are defined as the days you wake up and go to sleep at similar times)

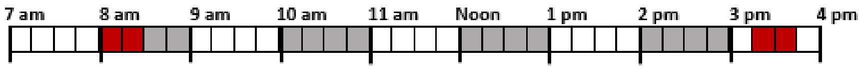
I work on ❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 days per week

8. Can you report on your typical sleep behaviour over the past 4 weeks?
Please, respond to the questions according to your perception of a standard week that includes your usual work days and work-free days and use a 24-hour time scale (e.g. 23:00 instead of 11 pm).

WORKDAYS	FREE DAYS
I go to bed at ______ **o'clock.** (Note that some people stay awake for some time when in bed)	I go to bed at ______ **o'clock.** (Note that some people stay awake for some time when in bed)
I actually get ready to fall asleep at ______ **o'clock.**	I actually get ready to fall asleep at ______ **o'clock.**
I need ____ **minutes** to fall asleep.	I need ____ **minutes** to fall asleep.
I wake up at ______ **o'clock.**	I wake up at ______ **o'clock.**
After ____ **minutes** later, I get up.	After ____ **minutes** later, I get up.
I use an **alarm clock** on workdays: ❑ Yes ❑ No	I use an **alarm clock** on free days: ❑ Yes ❑ No
If yes, I regularly wake up **before** the alarm rings ❑ Yes ❑ No	

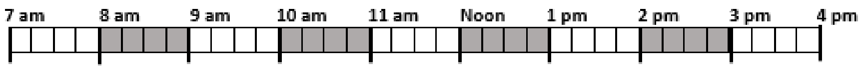
9. Please, fill the gap describing your exposure to natural light outdoors on average **<u>during a typical day in the last 4 weeks.</u>** (without a roof above your head) (each cell represents **<u>15 minutes</u>**)

<u>For example:</u>

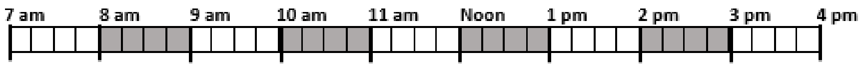


"I spent time outside under the sky at 8:00-8:30 and 3:15-3:45 in a typical day of my last 4 weeks."

<u>On workdays:</u>



<u>On free days:</u>



10. Why did you select **this desk** to sit down? (Please indicate **at least one reason** with importance order. First one is the most important reason and third one is the least)

1. ______________________________
2. ______________________________
3. ______________________________

11. Is it your preferred seat?
(If it is not your preferred seat, please indicate your best place in the plan drawing in Question 18 with reason)

- ❑ **Yes**, it is my <u>preferred seat.</u>
- ❑ **No**, I tend to sit here <u>whenever possible.</u> (seat place is not important for me)
- ❑ **No**, I sat here because my preferred seat <u>was not available</u> (e.g. someone else was sitting there)

12. How long have you been sitting at this place?
- ❑ Less than 30 minutes
- ❑ 30 minutes -1 hour
- ❑ 1- 2 hours
- ❑ More than two hours

13. How would you describe the indoor environmental quality **in this room**?

Indoor air quality	Unsatisfactory	☐	☐	☐	☐	☐	☐	☐	Satisfactory
	Dry	☐	☐	☐	☐	☐	☐	☐	Humid
	Fresh	☐	☐	☐	☐	☐	☐	☐	Stuffy
	Odourless	☐	☐	☐	☐	☐	☐	☐	Smelly
Light overall	Unsatisfactory	☐	☐	☐	☐	☐	☐	☐	Satisfactory
Natural light	Too little	☐	☐	☐	☐	☐	☐	☐	Too much
Artificial light	Too little	☐	☐	☐	☐	☐	☐	☐	Too much
Temperature	Unsatisfactory	☐	☐	☐	☐	☐	☐	☐	Satisfactory
	Too hot	☐	☐	☐	☐	☐	☐	☐	Too cold
Noise overall	Unsatisfactory	☐	☐	☐	☐	☐	☐	☐	Satisfactory
Noise from people	Too little	☐	☐	☐	☐	☐	☐	☐	Too much
Noise from outside	Too little	☐	☐	☐	☐	☐	☐	☐	Too much

Please, **tick the most representative one** describing your perceptions in the following questions:

14. How do you describe **the amount of daylight** at your seat/ on your desk?

Very low	Low	Below average	Above average	High	Very high
☐	☐	☐	☐	☐	☐

15. How do you describe **the uniformity of daylight** in this room?
(The uniformity of daylight represents if daylight varies within the room or not. If it is uniform, it means that you perceive similar features of daylight amount within all parts of the room)

Very low	Low	Below average	Above average	High	Very high
☐	☐	☐	☐	☐	☐

16. How do you describe **the degree of glare** that you experience when viewing the windows?
(Glare is a visual sensation caused by excessive and uncontrolled brightness)

Very low	Low	Below average	Above average	High	Very high
☐	☐	☐	☐	☐	☐

17. How do you feel about your **overall level of visual comfort** in this room?

Very dissatisfied	Moderately dissatisfied	Slightly dissatisfied	Slightly Satisfied	Moderately satisfied	Very satisfied
☐	☐	☐	☐	☐	☐

18. Please, select the desk which you're currently sitting from below plan drawing and write down current date and time accurately. (If it is not your preferred seat, please indicate your best place in below plan drawing with reason)

DATE:
TIME:

My actual desk **(X)**

My preferred desk **(O)**

Reasons:
____
____
____

Appendix 6: The median external diffuse horizontal illuminance of the cities where participants spent the majority of their lives and last years

COUNTRY	CITY	Median External Diffuse Illuminance	Latitude
Indonesia	**Pekanbaru**	23307	0.46
Singapore	**Singapore**	27021	1.36
Malaysia	**Kuala Lumpur**	26243	2.75
Colombia	**Bogota**	29531	4.70
Africa	**Abidjan**	28554	5.26
Malaysia	**Penang**	28987	5.30
Indonesia	**Jakarta**	23472	-6.18
Indonesia	**Bandung**	24497.5	-6.90
Indonesia	**Denpasar**	25985	-8.75
Venezuela	**Caracas**	21408	10.49
Colombia	**Barranquilla**	26685	10.89
Peru	**Lima**	26222.5	-12.02
Thailand	**Rayong**	27409	12.63
Thailand	**Bangkok**	28700	13.92
India	**Mumbai**	24500	19.12
China	**Zhanjiang**	21955	21.15
HongKong	**HongKong**	21840.5	22.31
Chile	**Antofagasta**	19392.5	-22.50
China	**Shenzen**	26309	22.64
India	**Kolkata**	18728	22.66
China	**Guangzhou**	16947.5	23.17
Brazil	**Sao Paulo**	18183	-23.50
Taiwan	**Taichung**	18971	24.15
China	**Xiamen**	24612	24.54
Pakistan	**Karachi**	19399	24.91
Taiwan	**Taipei**	20800	25.07
Paraguay	**Asuncion**	23411	-25.24
China	**Chenzhou**	21037	25.74
Africa	**Johannesburg**	19208	-26.14
Australia	**Brisbane**	17741	-27.48
China	**Wenzhou**	22551	28.02
China	**Changsha**	21096	28.12
India	**Delhi**	18100	28.58
USA	**Texas**	15174	29.11
China	**Chongqing**	23500	29.52
China	**Ningbo**	21991	29.92
Egypt	**Cairo**	19300	30.13
China	**Hangzhou**	21797	30.23

China	**Wuhan**	25500	30.62
China	**Chengdu**	24500	30.67
China	**Shanghai**	23300	31.17
China	**Suzhou**	20752	31.27
USA	**Waco**	14329.5	31.62
Israel	**Jerusalem**	16989	31.77
Israel	**Tel-Aviv**	16569.5	32.00
China	**Nanjing**	24700	32.00
China	**Xinyang**	20801	32.13
Argentina	**Mendoza**	17903	-32.83
China	**Nanyang**	20345	33.10
Chile	**Santiago**	16798	-33.43
USA	**Atlanta**	13807	33.63
USA	**California-Irvine**	-	33.66
Lebanon	**Beirut**	17017	33.82
China	**Xuzhou**	18555	34.28
Argentina	**Buenos Aires**	21120	-34.56
Japan	**Osaka**	15017	34.68
Japan	**Kyoto**	14971	35.02
China	**Yuncheng**	19013	35.11
China	**Anyang**	16538	36.05
Syria	**Aleppo**	23334	36.18
Japan	**Tokyo**	17300	36.18
Iran	**Mashhad**	19222	36.24
China	**Qingdao**	22211.5	36.27
China	**Jinan**	15926	36.60
Turkey	**Mersin**	21082	36.80
Turkey	**Gaziantep**	19041	36.95
New Zealand	**Auckland**	20391.5	-37.00
Turkey	**Mardin**	17715	37.30
China	**Weihai**	19036	37.52
Korea	**Seoul**	16739	37.57
Australia	**Melbourne**	20581	-37.67
China	**Taiyuan**	12258	37.78
Greece	**Athens**	18600	37.90
Greece	**Piraeus**	20082	37.92
Turkey	**Konya**	19543	37.98
USA	**Chicago**	12460	38.05
China	**Jinchang**	16642	38.47
China	**Yinchuan**	15848.5	38.47
China	**Tianjin**	15472	39.10
China	**Tangshan**	18142	39.65
China	**Beijing**	19400	39.93
Turkey	**Ankara**	17955	39.95
USA	**New Jersey-Trenton**	16400	40.28

Greece	**Thessaloniki**	17695.5	40.52
Italy	**Brindisi**	17800	40.65
USA	**New York City**	18000	40.78
USA	**Long Island**	12994	40.79
China	**Hohhot**	17958	40.85
Spain	**Barcelona**	19490.5	41.29
Italy	**Rome**	18100	41.80
USA	**Boston**	12141	42.35
Kazakhstan	**Almaty**	20073.5	43.23
France	**Marseille**	17874	43.44
New Zealand	**Christchurch**	20084	-43.49
Canada	**Toronto**	13361.5	43.62
China	**Urumqi**	9127	43.78
Italy	**Genoa**	17601	44.41
Romania	**Bucharest**	17803	44.51
Italy	**Milan**	17300	45.62
Switzerland	**Geneva**	17329.5	46.24
Switzerland	**Nyon**	18529.5	46.40
Switzerland	**Lausanne**	16160.5	46.53
France	**Nantes**	17551.5	47.15
China	**Qiqihar**	16002	47.24
Hungary	**Budapest**	15325	47.43
Kazakhstan	**Mugalzhar**	15564	48.58
France	**Paris**	17484	48.78
Luxembourg	**Steinsel**	17253	49.62
Germany	**Frankfurt**	17797.5	49.96
Czech Republic	**Prague**	14000	50.10
Poland	**Katowice**	17619	50.23
UK	**Cornwall**	17286	50.43
UK	**Exeter**	16528	50.73
UK	**Brighton**	17316	50.84
Belgium	**Brussels**	16510	50.90
Kazakhstan	**Astana**	17127	51.02
UK	**Bristol**	16939	51.38
UK	**Cardiff**	16794	51.40
Ireland	**Cork**	16899.5	51.84
UK	**Cheltenham**	16561.5	51.89
UK	**London**	13300	51.51
Poland	**Warsaw**	15694	52.17
UK	**Cambridge**	16490	52.21
Netherlands	**Amsterdam**	16020.5	52.32
UK	**Birmingham**	15100	52.45
Germany	**Hannover**	15204	52.46
Germany	**Berlin**	13000	52.47
UK	**Nottingham**	14208	53.00

UK	**Liverpool**	16008	53.33
UK	**Manchester**	15896	53.35
UK	**Sheffield**	16108	53.48
UK	**Blackpool**	15969	53.77
UK	**Leeds**	15719	53.80
UK	**Newcastle**	14902.5	54.98
Denmark	**Copenhagen**	15654.5	55.61
UK	**Glasgow**	14735	55.87
UK	**Edinburgh**	15378.5	55.95
UK	**Dundee**	15470	56.45
Sweden	**Stockholm**	12349	59.35
Norway	**Oslo**	14187.5	60.21
Norway	**Roros**	13284	62.57
Norway	**Trondheim**	11885	63.41

Appendix 7: Published works and plans

Appendix 7.1: A published research article entitled with "Evaluation of Daylight Perception Assessment Methods"

Article title	Evaluation of Daylight Perception Assessment Methods
Authors	Gizem Izmir Tunahan, Hector Altamirano, Jemima Unwin Teji and Cosmin Ticleanu
Journal title	Environmental Psychology, a section of the journal Frontiers in Psychology
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frontiers | Frontiers in Psychology

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Evaluation of Daylight Perception Assessment Methods

Gizem Izmir Tunahan[1], Hector Altamirano[1], Jemima Unwin Teji[1] and Cosmin Ticleanu[1,2]*

[1]*UCL Institute for Environmental Design and Engineering, The Bartlett, London, United Kingdom,* [2]*BRE (Building Research Establishment), Hertfordshire, United Kingdom*

Daylight is an important component in maintaining human health and wellbeing and plays a key role in physiological, psychological, and behavioural regulation. Understanding the complexity of daylight perception is vital since the degree of satisfaction with daylight conditions could greatly impact individual mood, behaviour and cognitive performance. This paper aims at (1) presenting an overview of current knowledge on methods for assessing daylight perception and (2) establishing a methodology for assessing daylight perception in the context of cultural background. An experiment was conducted with 50 students who were instructed to select the best and worst seats, describe the best desks' daylight conditions and draw boundary lines between perceived daylit and non-daylit spaces in a library. The study showed that subjective rating and seat preference methods were consistent with actual daylight levels. However, participants' boundary lines did not represent the actual daylight availability in the space. The study suggests that individual daylight perception in the context of cultural background can be assessed using the subjective rating and seat preference methods.

Keywords: daylight availability, daylight perception, seat preference, drawing, environmental behaviour, method evaluation

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****Correspondence:***
Gizem Izmir Tunahan
gizem.izmir.tunahan.17@ucl.ac.uk

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INTRODUCTION

The characteristics of an indoor lighting environment could significantly affect the comfort, wellbeing and productivity of building occupants (Al horr et al., 2016). The lighting quality assessment typically includes photometric measurements, which does not provide a complete representation of an environment's lighting quality (Allan et al., 2019). The assessment should not only consider the links between the lighting levels and the characteristics of the space where light is measured but, more importantly, how people perceive that environment. As of today, far too little attention has been paid to daylight perception and its evaluation methods, as highlighted by the Commission Internationale de l'Eclairage 2013 (CIE 213, 2014) and the Dubois et al. (2016). Understanding its complexity and potential benefits could be crucial, especially in the context of health and wellbeing, mood, and also cognitive and academic performance. Up to now, several studies have shown that exposure to different amounts and characteristics of daylight could enhance students' cognitive performance (Shishegar and Boubekri, 2016; Jamrozik et al., 2019). However, it is still not known how students' daylight perceptions and preferences and the level of daylight they are satisfied will contribute to their academic performance.

Culture, one of the essential components of an individual, delineates the characteristics of a group with similarities such as language, religion, tradition, and ethnicity. Knowing the cultural background of a group of people is vital because it could help understand why a group of people acts similarly compared to another group. Lighting research to date has tended to focus on the impact of cultural background on glare discomfort perception rather than daylight perception and satisfaction. Most cross-cultural lighting studies have examined discomfort glare perception and colour temperature preference, but they did not sufficiently focus on the adequacy of illuminance levels. Cross-cultural studies aiming to investigate lighting preferences in interior environments are rare and what is not yet known is the importance of cultural background and its impact on daylight perception, expectation and satisfaction.

In the field of lighting environment, Pierson et al. (2018) have used the term of 'culture' as '*the climatic and indoor conditions to which the subject has been accustomed during the major part of his/her life, his/her behaviour toward this indoor environment, and his/her expectations about it*'. Subsequently, a recent study (Izmir Tunahan et al., 2021) has highlighted the importance of cultural background in daylight perception and suggested that the cultural background in the lit environment should be evaluated, considering (1) the ethnicity and/or physiological characteristics of the individual eyes, (2) the area (luminance environment) where people used to live, (3) the luminance environment they were recently exposed to, and (4) the socio-cultural background of individuals.

In the United Kingdom, students constitute 19% of higher education (equals to 438,010 students) with 13.6% of undergraduate, 36.6% of postgraduate (taught) and 43.2% of postgraduate (research) students. They travel mostly from countries with a wide range of daylight conditions that differ from each other and from daylight conditions in the United Kingdom (e.g., China, Malaysia, the United States, Nigeria, India, Germany, France, Italy and Ireland; UKCISA, 2017). Outside daylight conditions refer to the amount and duration of daylight varying with the sun's position in the sky depending on latitude and atmospheric conditions that depend on various factors (e.g., turbidity, climate and pollution). Hence, students from different parts of the world could be assumed to have previously experienced different lighting environments and students from locations with similar daylight conditions should have comparable daylight expectations. To this end, students' cultural diversity and the specific lighting environments they were previously accustomed to could affect their perception and expectation towards the outdoor and indoor conditions they found in the United Kingdom (Izmir Tunahan et al., 2021).

Maintaining the students' satisfaction with the indoor environment they found in the United Kingdom is considerable because the indoor environmental quality is highly associated with the occupants' health and wellbeing (Sakellaris et al., 2016). The degree of satisfaction, in particular with daylight conditions, greatly impacts individual mood, behaviour and cognitive performance (Wang and Boubekri, 2011). Therefore, gaining a better understanding of students' daylight perception and expectations could increase their satisfaction with the indoor environment and also cognitive and academic performance. This knowledge can also be utilised by managers and daily operators of university buildings to help reduce the energy consumption of HVAC (Heating, Ventilation, and Air Conditioning) and illumination systems. For instance, a study on Korean office buildings showed that adjusting the indoor lighting conditions based on occupants' expectations and utilisations helps to reduce lighting energy consumption by up to 43% (Yun et al., 2012). Moreover, it can support architects and lighting professionals working in the design of educational and residential buildings.

In order to maintain the satisfaction and academic performance of the students from different cultural backgrounds in the indoor environment they found in the United Kingdom, we needed to develop a methodology for assessing daylight perception. Therefore, this paper aims to (a) review the methods previously used to assess daylight perception and (b) establish a methodology for assessing daylight perception in the context of cultural background.

THE HUMAN RESPONSE TO DAYLIGHT: EVALUATION METHODS

In order to create a framework of the methodological approach to assess daylight perception in the literature, 482 research articles published in Scopus, Web of Science, and LEUKOS databases were searched for electronic records. The search was done in either title, abstract, or keywords of the papers using the following keywords: (Day)light perception, (Day)light expectation, (Day)light satisfaction, (Day)lighting sensitivity, (Day) lighting tolerance and (Day)light adaptation. The inclusion criteria were: (a) including at least one aspect of (day)lighting perception, (b) published in English, peer-reviewed journals excluding conference proceedings and books, and (c) published during any year from 1990 to November 2021. Relevant articles were classified depending on their methods and reported in **Tables 1–3**.

General Methodological Approach in the Reviewed Studies

Various methods have been developed and used to investigate how lighting conditions are consistent with human perception of daylight and daylight expectations. These methods have been applied in either real-world environments (Keskin, 2019) or laboratories under specified testing conditions (Chamilothori et al., 2016; Chinazzo et al., 2019; Yasukouchi et al., 2019).

Even though real-world environments provide an opportunity to conduct studies in a dynamic social context, people being observed cannot be tested under diverse environmental conditions. Conversely, participants in laboratory settings know they are the subject of study, which may affect their behaviour, making it challenging to associate results with real-life situations (Keskin, 2019). Nevertheless, laboratory studies enable researchers to investigate changes when daylight conditions are changed (Figueiro et al., 2011; Karami et al., 2016), which cannot be tested in real-world environment studies.

Although most methods and tools used in assessing daylight perception differ, their general methodological approach is similar; it combines subjective and objective measurements

TABLE 1 | The methods for circadian rhythm related assessment.

Method		References
Cognitive performance	**n-back test** *to measure working memory and working memory capacity*	Jaeggi and Jaeggi, 2011
	CNV test *to measure work performance with the average response times of correct answers*	Yasukouchi et al., 2019
	Arithmetic task *to reflect work performance with the ratio of correct answers*	
	Tsai Partington *to evaluate the distributed visual attention*	Chinazzo et al., 2019
	d2 test *to evaluate the sustained vigilance* **Baddeley test** *to evaluate the logical reasoning*	
	Psychomotor Vigilance Test (PVT) *including a Simple Reaction Time (SRT) test, a 2-Forced Choice Reaction Time (FCRT) test, and a Matching-to-Sample (MTS) test.*	Figueiro et al., 2011
	Observation of Typing speed and accuracy	Shamsul et al., 2013
	Eye-tracking *for measure numbers of fixation with a device such as Tobii® T60 Eye Tracker*	Shamsul et al., 2013
	Class attendance *as a measure of students' performance*	Edwards and Torcellini, 2002
Alertness	**Visual Analogue Scale (VAS)** *to assess fatigue and alertness*	Karami et al., 2016
	Karolinska Sleepiness Scale *to measure both subjective sleepiness and alertness*	Shamsul et al., 2013; Chinazzo et al., 2019
Sleeping pattern	**Subjective sleepiness** *with some surveys such as the 9-item Karolinska Sleepiness Scale (KSS) and Sleep Habits Survey*	Figueiro et al., 2011; Jaeggi and Jaeggi, 2011; Figueiro et al., 2014; Karami et al., 2016; Choi et al., 2019
	Sleep-activity behaviour	Adamsson et al., 2018
	A daily sleep-activity graph during the experiment	
	Identification of morningness-eveningness	Chung, 2009; Jaeggi and Jaeggi, 2011; Figueiro et al., 2014; Adamsson et al., 2018
	Horne and Ostberg Morningness-Eveningness Questionnaire, Munich Chronotype Questionnaire (MCTQ) and Composite Scale	
Mood	*Psychosocial stress assessing with Perceived Stress Scale (PSS)*	Figueiro et al., 2011
	Mood *assessing with the Positive and Negative Affect Schedule (PANAS), and the Centre for Epidemiologic Studies Depression Scale (CES-D)*	Figueiro et al., 2011
	Subjective general health evaluation *using GHQ questionnaire*	Karami et al., 2016
	Subjective mood and visual comfort using *visual analogue scales (VASs)*	Choi et al., 2019

and assesses them depending on the existing lighting conditions collected by either spot measurements or daylighting simulations. The studies are also often supported by circadian rhythm parameters, such as cognitive performance, alertness, sleep quality, and mood. Nevertheless, almost all studies have used one or more methods to assess the changes occurring in daylight perception concerning the variation in the luminous environment.

Methods Regarding Circadian Regulation

Circadian rhythms are approximately 24-h cycles controlled by an internal master clock in the brain responsible for regulating many physiological (body temperature and hormones) and behavioural (sleep, mood, alertness and performance) changes (Skene and Arendt, 2006). Circadian rhythms are mainly affected by the intensity and timing of light exposure (Arguelles-Prieto et al., 2019) and adjusted at regular intervals by receptors transmitting non-image-forming information of light, which activate the circadian system (Bellia et al., 2011).

Exposure to a high amount of daylight (for example, spending a large amount of time outside or sitting indoors by a big window) has been shown to be related to enhancer effects in students' cognitive and academic performance (Shishegar and Boubekri, 2016). Previous research that examined the impact of different shading systems on cognitive function performance, satisfaction, and eyestrain in a living lab has also established that satisfaction with indoor daylight conditions could result in higher cognitive performance (Jamrozik et al., 2019). Most researchers have benefitted from commonly used tests and techniques such as the Psychomotor Vigilance Test (PVT), usually used to assess the link between daylight and cognitive performance. Others have also used class attendance or typing speed and accuracy as an indicator of cognitive performance.

On the other hand, several studies have proved that daylight exposure significantly influences occupants' mood state (Boyce et al., 2003). Küller et al. (2006) indicated that the participants' mood reached the lowest level when describing the daylight conditions as too insufficient. Specified scales (PSS, PANAS, CES-D and VASs; Figueiro et al., 2011; Choi et al., 2019) and questionnaires (GHQ; Karami et al., 2016) are usually utilised to investigate the association between the exposed daylight conditions and mood states.

Changes in circadian rhythms have also been associated with sleep quality and alertness in addition to mood and cognitive performance (Garbarino et al., 2020). The Karolinska Sleepiness Scale (KSS) has been mainly used to measure both subjective sleepiness and alertness (Shamsul et al., 2013; Chinazzo et al., 2019). Tools such as the Horne and Ostberg Morningness-Eveningness Questionnaire and the Munich Chronotype Questionnaire have also been used to assess the sleep quality of participants grouped according to their sleep–wake behaviour (morningness–eveningness; Jaeggi and Jaeggi, 2011; Adamsson et al., 2018).

TABLE 2 | The methods for subjective daylight assessment.

Method		References
Interviews	*Informal or semi-structured*	Axarli and Meresi, 2008; Dianat et al., 2013; Gentile et al., 2015; Yasukouchi et al., 2019
Questionnaires	**Questionnaire-based survey** *Snapshot subjective assessments such as Perceived lighting quality assessment and other created questionnaires mainly using a semantic differential method*	Cheung and Chung, 2008; Dianat et al., 2013; Gentile et al., 2015; Adamsson et al., 2018; Bournas et al., 2019; Chamilothori, 2019; Chinazzo et al., 2019
	Questionnaire-based survey *Long term subjective assessments*	Jakubiec et al., 2018
	Subjective evaluations *during experiments within different kinds of room (geometry/orientation/window type/façade type), different locations and different contexts (social or working context)*	Axarli and Meresi, 2008; Chamilothori et al., 2016, 2018, 2019; Bian and Luo, 2017; Jin et al., 2017
	Visual comfort evaluation *such as Visual comfort on visual analogue scales (VAS), Office Lighting Survey (OLS), Lighting Conditions Survey, NRC Canada Lighting Quality Scale, IEA retrofit monitoring user assessment survey, Indoor Environmental Quality Surveys*	Jaeggi and Jaeggi, 2011; Shamsul et al., 2013; Bian and Luo, 2017; Adamsson et al., 2018; Alicia et al., 2019
	Indoor Environmental Quality Surveys *such as Satisfaction with Environmental Features and Subjective ratings of discomfort glare (De Boer scale, Imperceptible-intolerable 4-point scale, Glare Sensation Vote, Visual comfort rating)*	Alicia et al., 2019
	Other subjective measures of lighting *Descriptive scales and Lighting preferences, beliefs, and behavioural consequences*	Alicia et al., 2019
	Verbal questionnaire *Evaluation of the impressions of how pleasant, interesting, and exciting the space*	Chamilothori et al., 2019
	Questionnaires *distributed by mail to evaluate brightness and distribution*	Bournas et al., 2019
Quantification of daylight exposure consequently circadian light exposure	**Actigraphy data from wearable biometric devices** *during the experiment with wristbands such as Empatica E4 wristband*	Figueiro et al., 2014; Chamilothori et al., 2018, 2019; Chinazzo et al., 2020
	Actigraphy data from wearable biometric devices *during the experiment with the Daysimeter*	Rea et al., 2010
	Actigraphy data from wearable biometric devices *during the experiment with the ambulatory circadian monitoring device (ACM)*	Arguelles-Prieto et al., 2019
	Actigraphy data from wearable biometric devices *prior to the study beginning, withbed and wake times with wristbands such as Actiwatch-L*	Chung, 2009;Jaeggi and Jaeggi, 2011; Yasukouchi et al., 2019
	Actigraphy data from wearable biometric devices *prior to the study beginning, with bed and wake times with the Daysimeter*	Figueiro et al., 2011
	Asking time spent outdoors *such as The Munich Chronotype Questionnaire (MCTQ), the Harvard Light Exposure Assessment questionnaire or self-prepared questions to get data about light exposure*	Adamsson et al., 2018
Logs	**Weekly log** *ratings of psychological well-being, daily sleep-activity and time spent outdoors*	Adamsson et al., 2018
	Daily sleep log *prior to the study beginning.*	Jaeggi and Jaeggi, 2011; Yasukouchi et al., 2019
Seat preference	**Surveys and observations** asking for the reasons for the choice of seat locations and direct observations of actual seating behaviour	Organ and Jantti, 1997; Kim and Wineman, 2005; Wang and Boubekri, 2010; Othman et al., 2012; Keskin et al., 2017; Gou et al., 2018
Drawings	**Drawing daylight boundary line** *between daylit and non-daylit area*	Reinhart and Weissman, 2012; Handina et al., 2017
HDR-High dynamic image techniques		Jin et al., 2017; Jung and Inanici, 2019; Chinazzo et al., 2020
Daylight 3D renderings	**Showing the renderings** *with the computer software of the same space to the subjects and ask to rate daylight composition*	Rockcastle and Andersen, 2015
Immersive virtual reality (VR)	**VR with headsets** *such as Oculus Rift CV1 and Oculus Rift DK2*	Chamilothori et al., 2016, 2018, 2019; Chamilothori, 2019

Physiological Biomarkers as a Consequence of Exposure to Daylight

Physiological measurements (biomarkers) are regarded as indicators of previous light exposure; in other words, how much a participant was exposed to light during a specific time. The duration, timing and intensity of exposed daylight may affect people's satisfaction with current daylight conditions and the regulation of their circadian rhythms. Thus, the assessment of physiological biomarkers could play a crucial role in assessing and interpreting an individual's daylight perception.

The objective measurement of daylight perception considers the assessment of physiological biomarkers such as heart rate (Chamilothori et al., 2019; Chinazzo et al., 2020), skin conductance (Chamilothori, 2019; Chamilothori et al., 2019), core body temperature (Chung, 2009; Chinazzo et al., 2020), cortisol level (Jaeggi and Jaeggi, 2011; Choi et al., 2019), and melatonin secretion (Figueiro et al., 2011; Jaeggi and Jaeggi, 2011).

TABLE 3 | The methods for objective measurements.

Method	References
Heart rate (HR) using some devices such as Empatica E4 wristband	Chamilothori et al., 2018; Chamilothori et al., 2019; Yasukouchi et al., 2019; Chinazzo et al., 2020
Skin conductance (SC) using some devices such as Empatica E4 wristband and Electrodermal activity (EDA) wristband	Chamilothori et al., 2018, 2019; Chinazzo et al., 2020
Core body temperature using some devices such as iButtons data loggers and wristband	Chung, 2009; Chinazzo et al., 2020
Cortisol level from salivary	Jaeggi and Jaeggi, 2011; Choi et al., 2019
Melatonin secretion from salivary, blood, urine	Figueiro et al., 2011; Jaeggi and Jaeggi, 2011; Tähkämö et al., 2015; Karami et al., 2016; Choi et al., 2019; Yasukouchi et al., 2019

Heart rate, skin conductance, and body temperature have been measured using wristbands, while melatonin secretion is measured using either salivary, blood, or urine samples.

Subjective Assessment of Daylight

Since individuals are physically and psychologically influenced by daylight (Chung, 2009), objective measurements should be complemented with subjective evaluations. However, some studies (Galasiu and Veitch, 2006; Bellia et al., 2017; Lo Verso et al., 2021) have shown that correspondence between exposed daylight conditions and subjective assessment of the occupants is not always observed because of individual differences. Subjective assessment methods mainly use questionnaires to obtain information through semantic differential techniques, measuring the participant's overall reaction to specific factors such as ambient illumination of different light sources or horizontal illuminance and brightness of a space (Jin et al., 2017; Albertazzi et al., 2018). Similarly, open-ended questions are used to gain deeper and new insights into the feelings towards daylight conditions, for instance, asking how participants describe the lighting conditions and how they feel under those conditions. Information is usually collected concerning the participants' background (age, gender, work schedule, sleep and wake times, previous daylight exposure etc.), their evaluation of daylight illuminance and distribution, and their general satisfaction with the indoor environment (Levin, 2017).

As a method for assessing previous daylight exposure, questionnaires require participants to estimate the frequency of exposure to daylight in a particular period (Adamsson et al., 2018). For instance, the Munich ChronoType Questionnaire (MCTQ) involves estimating the time spent outdoors on workdays and free days, assuming regular light exposure patterns. Likewise, the Harvard Light Exposure Assessment questionnaire (H-LEA) emphasises the importance of time duration and period of light exposure during the daytime to various artificial and natural light sources. Information about previous daylight exposure is also collected with the use of devices that participants are asked to wear, for example wristbands, Daysimeter and ACM (Chamilothori et al., 2019) before (Figueiro et al., 2011) and/or during the experiment (Rea et al., 2010). The collected data is often supported by self-written logs (Adamsson et al., 2018). These devices are also used to gain insight into the activity and sleep pattern of the participants and the amount of daylight they were exposed to.

Few researchers have preferred other subjective methods such as interviews to test the influence of different daylighting configurations on participants' daylight perception (Dianat et al., 2013; Gentile et al., 2015). Moreover, the use of evaluation techniques, such as seat selection, have been applied, where it has been assumed that daylight perception and expectation are associated with seat preference and window location (Wang and Boubekri, 2010; Keskin et al., 2017). In this case, the selected desk's illuminance level could be used as an indicator of daylight perception. Additionally, a unique method was proposed by Reinhart and Weissman (2012) and also used by Handina et al. (2017), given its potential as a representation tool of how daylight composition can be perceived in a space. Handina et al. (2017) have considered the daylight boundary line method to assess perception through the definition of daylit and non-daylit areas drawn by participants. In this methodology, participants have been required to draw a line whenever they notice a boundary between brightness and darkness in the experiment room. Their initial results showed that the percentage of the area enclosed with the contour line of DA300 lx, 50% (illuminance level of at least 300 lux over at least 50% of the space) in the observed space (55%) is close to the partially daylit area (56%), which is the area perceived as bright by at least 25% of participants. Furthermore, high Dynamic image techniques (Jung and Inanici, 2019) and 3D daylight renderings (Rockcastle and Andersen, 2015) have also been used to evaluate the human perception of the daylight composition found in shown scenes. In the further development of these techniques, subjective daylight perception under various computer-generated conditions has been assessed using scenes displayed with the Immersive virtual reality (VR) technique (Chamilothori et al., 2016).

METHODOLOGY

Fifty MSc students were brought all together to the Bartlett Library, asked to complete a questionnaire before the experiment and undertake a set of tasks while going around the library. The library was assessed during one of the sunniest days in December 2019 (between 13:00 and 14:00); a day with a clear sky was selected to get maximum daylight throughout the library during the experiment. The day and time of the study were decided based on both the previous years' daylighting data obtained from Public Health England and weather data from the Met Office. All tasks took between 20 and 25 min to complete. Collected subjective responses from participants were evaluated depending on the daylight availability of the room obtained from a lighting simulation tool.

As previously highlighted, the effect of lighting conditions on human perception and expectations should be investigated using objective measurements and subjective evaluations. However, only subjective evaluation methods with different applications could be utilised to complement each other for situations where a considerable amount of data collection from objective measurements may not be feasible and accessible. Thus, in this study, only these subjective evaluation methods were applied; seat preference, subjective ratings and daylight boundary line drawings.

Participants

An invitation to participate in the study was sent *via* email to 348 postgraduate students enrolled in MSc programs at the Bartlett School of Architecture, UCL. Seventy-six responded that they would be happy to be involved in the experiment, but only 50 students (15 males/35 females) aged 20–34 years old were recruited for this study.

In terms of cultural background, the ethnicity of participants and the time spent in London were considered. Eleven participants (22%) described themselves as White, whereas 33 students (66%) stated they have an Asian background. Only five participants (10%) defined their ethnicity as other ethnic backgrounds. Most of the students (72%) were overseas students who had spent less than 3 months in London.

Field Site

The study was carried out in the UCL Bartlett library located on the ground floor of a six-storey building. The library comprises three main study areas (**Figure 1**). The group study area (Room 1) accommodates eight shared desks and four individual cubicles and has two side windows in the north-facing external wall; the library collection area (Room 2) has 12 shared desks and 11 individual desks and several side windows facing north and east orientations; the quiet study room (Room 3) is an open-plan space with a skylight, and 32 shared desks. Details of the rooms and technical properties of the surfaces are illustrated in **Appendix 1**.

Quantification of Daylight Availability in the Library

Parametric modelling and daylight simulations were used to get information concerning daylight availability at desks in each room at the library. Spot illuminance measurements were also used to calibrate the created model. AutoCAD and Rhino were used to produce 2D and 3D drawings of the library. Then, Grasshopper was used to create parametric modelling for lighting performance analysis with Ladybug and Honeybee plugins.

Previous studies show that computer predictions with simulation methods demonstrate higher accuracy than measurements taken in real-world conditions. The simulation method results involve an acceptable amount of error arising from either unpredictable sky conditions at that moment or the incorrect input parameters in the simulation model. Therefore, it is always more reliable to compare daylight performance predictions obtained from computer simulations with physical measurements taken in the real space. Since it demonstrates how much simulation results correspond to actual daylight conditions. Daylight modelling built-in Radiance was validated against actual illuminance measurements at a specific point, date and time. A strong association between simulation results and actual daylight measurements was found ($p < 0.05$, $R^2 = 0.89$). In other words, the difference in values between spot measurements and simulation results are negligible, and simulation results represent the real daylight illuminances with an acceptable error range.

Contribution of Electric Light to Total Illuminance

On the day in which the study was performed, students were exposed to electric light in addition to daylight.

The contribution of electric light to total illuminance was investigated by measuring the electric light illuminances in the middle of each desk using a Konica Minolta Illuminance meter T-10A on the 30 November 2019 between 16:45 and 17:15 after sunset. Thereafter, these illuminances were compared with total illuminance measurements taken during the experiment. The electric light illuminance values on the work planes were found highly correlated with the total illuminance measurements ($p = 0.001$). For this reason, it was assumed that all desks receive the same amount of electric lighting, and therefore variations between them would be due to daylight alone.

Subjective Daylight Assessment Methods

Questionnaire Design

A questionnaire was designed to include the three methods used in this study: seat preference, subjective rating, and daylight boundary line drawings. The questionnaire contained multiple-choice, Likert scale, and open-ended questions and was divided into five sections; the first two sections of the questionnaire were completed by participants before entering the library and considered information regarding (1) demographic; gender, and age, (2) time spent in London (months). The following three sections considered specific questions and tasks related to the methods explored to measure participants' daylight perception; (3) seating preference and reasons for seat selection, (4) evaluation of daylight availability at the best seat selected, and (5) differentiation between daylit and non-daylit spaces (boundary line drawing). The procedure order was specifically designed to start with open questions regarding seat preference, and after then daylight specific questions to lead on to influence the participants' responses, thus the latter questions would not impact the responses to the former ones. Ethical approval for this study was obtained from the UCL Research Ethics Committee in November 2019.

Task 1: Seat Preference

Seating that meets students' needs and preferences could promote a longer stay in the libraries and keep students motivated,

FIGURE 1 | Plan of the Bartlett Library (The red arrows represent the locations from where the photos on the right side of the figure were taken).

influencing their emotions and learning abilities. Many disciplines have extensively discussed the influential factors on seat preference in a learning environment. It has been shown that the affecting factors arising from the physical environment that govern the decision of seat selection are daylight (Othman and Mazli, 2012; Keskin et al., 2017), ambient temperature, type of furniture, proximity to other occupants (Dubois et al., 2009), quietness, outdoor view, privacy, social interactions such as close to friends, entrance or circulation (Gou et al., 2018), students' degree of territoriality and seat arrangements (Kaya and Burgess, 2007).

Even though the importance of daylight on seat preference varies from study to study depending on the function of the room, time interval, time of the day and year (Keskin, 2019), some researchers have proved that daylight is the most important reason for seat selection (Alicia et al., 2019; Izmir Tunahan et al., 2021a,b) and the most frequently chosen as a reason for seat selection (Keskin, 2019). Hence, in this study, it was assumed that seat preference could be used to understand whether participants valued the daylight component. The daylight availability of the selected desk was then considered to be an indicator of the daylight conditions the participant prefers. For this purpose, participants were asked to indicate the three best and the three worst seat locations from the library's seating plan, and within those categories, the most and least liked. They were also asked to specify the reasons for their selection to examine whether the selected desks (best and worst) coincide with those where daylight levels were high and low, respectively, hence if the daylight component is an influential factor when deciding where to sit.

Task 2: Subjective Ratings

The subjective rating method involves asking participants to describe the daylight conditions on a specific desk surface. This method has been utilised in many lighting studies, and many researchers have found participants' own perceptual statements compatible with actual daylight conditions. However, subjective evaluations may not represent daylight availability completely because of individual differences in some cases.

This method was applied to determine the degree to which subjective statements represent daylight availability in a space and investigate whether people perceive daylight conditions in line with actual measurements. The possible reasons causing the variation between actual measurements and people's perceptions could help identify ways to increase occupant satisfaction in the built environment. For this purpose, participants were asked to describe the amount of daylight at the best seat they have selected using a six-option scale derived from the BUS questionnaire (Leena, 2017; from very low to very high; **Figure 2**). Thus, daylight availability at a specific desk was tested depending on how participants perceived it.

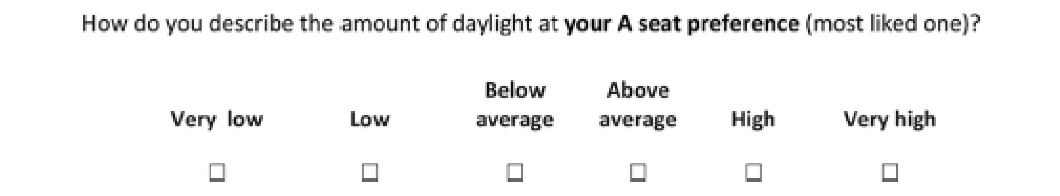

FIGURE 2 | The question regarding subjective ratings.

Task 3: Daylight Boundary Line

This unique method proposed by Handina et al. (2017) was used given its potential to represent how daylight composition can be perceived in a space. For this purpose, participants were instructed to draw on a copy of the library floor plan, 'daylight boundary lines', whenever a significant change of contrast was found or a bright area was perceived when moving around the library (**Figure 3**). The drawn boundary lines were then scanned and overdrawn in AutoCAD to overlay the perceived bright areas, which were assumed to indicate the perception of adequate daylight in this study. Finally, all drawings were superimposed on top of each other and evaluated based on daylight availability at a specific time.

Methods of Analysis

All the statistical analyses were conducted using the software package SPSS 20.0. Univariate descriptive statistics (response frequencies, means, and standard deviations) were calculated for each variable. Evaluations of the data obtained from three subjective methods were carried out separately as described below.

Analysis of Seat Preference

Initially, influential reasons for the best and worst seat selections and the importance of daylight in the selections were considered. Secondly, daylight availability at the best seat selected was evaluated using ordinal regression. Lastly, the best and worst seat selections were evaluated on the seating map concerning other influential factors on seat selections apart from the contribution of daylight.

Analysis of Subjective Ratings

Subjective ratings were evaluated based on the perceived daylight conditions towards daylight availability at the best seat selection using an independent-samples *t*-test.

Analysis of Daylight Boundary Line Drawings

Daylight boundary line drawings were assessed with the methodology created by Handina et al. (2017). Initially, the variation in participants' perceived bright area was analysed using descriptive statistic methods. Secondly, the statistical quartile concept was used to categorise and visualise the areas agreed by a certain number of participants as bright. Spaces were differentiated as *fully daylit* (area agreed as bright by at least 75% of the participants), *partially daylit* (area perceived as bright by at least 25%) and *non-daylit* (area perceived as bright by less than 25% of participants). Lastly, categorised areas representing the participants' overall daylight perception were overlapped with daylight availability to investigate if they correspond with each other.

Analysis of Daylight Simulations

Data obtained from seat preference and subjective rating methods were evaluated based on point-in-time climate-based calculations positioned horizontally in the middle of each working desk, which has been found to have a better association with seating behaviour than other daylight metrics for predicting daylight availability in previous studies (Keskin et al., 2015). Daylight boundary line drawings were assessed using DA300lx,50% (50% of the occupied time when the target illuminance of 300 lux on a horizontal plane is met by daylight) because of a more robust association with the daylight composition of space than others (Handina et al., 2017).

RESULTS AND DISCUSSION

Seat Preference

Reason for Seat Selection

Participants were instructed to select the three best and the three worst seats and indicate the reasons for their selection in an open-ended question. Each participant stated at least one reason for their seat selection (**Table 4**). The number of reasons stated for the seat selection was greater than the number of respondents who answered the question. This caused the total response percentages to exceed 100%.

Daylight was the most dominant reason when selecting the most liked desk, followed by privacy, outdoor view and quietness, respectively. These results align with the findings of Dubois et al. (2009); daylight was the most significant reason for seat selection. Keskin (2019) also reported daylight as a highly mentioned reason for seat selection in their experiment. In other respects, indoor conditions such as temperature and air quality were other influential parameters for seat selection. Other reasons mentioned related to specific desk features were wideness, proximity to the circulation route or entrance, enabling to study individually or with friends, being at the corner or the back of the room and access to facilities such as a computer or plug socket. The worst seats were also associated with unsatisfactory daylight conditions; and with distractive noise, lack of or unpleasant outside view and non-private environment.

FIGURE 3 | A few examples of participants' drawings in response to the question asking them to draw a boundary line between daylit and non-daylit spaces.

Although, in general, participants seem to agree on the reasons given when selecting the best and worst seats, there were a few cases where a particular desk was selected as the worst and the best by participants. Although seat preference varied from person to person depending on individual needs and expectancies, the majority of the participants considered it important to have a satisfactory daylighting level, face the least people, and have an outdoor view of greenery.

Daylight Availability at the Best Seats Selected

The daylight availability at the best desks selected by participants showed that 44% of the participants ($N = 22$) described the amount of daylight on their best desk as very high, 42% ($N = 21$) stated that the daylight conditions were high, and 6% ($N = 3$) as above average. In contrast, only 8% characterised the daylight conditions as low or very low. These results support the idea that most people prefer desks with a high amount of daylight, which could be with/without consciousness (Kahneman, 2011). Since the awareness of our behavioural responses to the physical environment is limited, and some of our behaviour is not under our conscious control.

An independent-samples t-test was also carried out to check whether there was a significant difference in daylight illuminance level of the best seats selected between participants who indicated daylight as the reason for their selection and those who did not. The findings showed that people who mentioned daylight as a reason preferred the desks with much higher daylight illuminance levels (468.5 ± 437.1 lx) than those that did not

TABLE 4 | Participants' responses concerning the reasons for choosing the best (left) and worst (right) seats in the library.

Reason for best seat selections	A best (%)	B second-best (%)	C third-best (%)	Reason for worst seat selections (%)	1 worst (%)	2 second-worst (%)	3 third-worst (%)
Quietness	14.3	4.0	7.7	**Noisy**	19.2	12.5	13.0
Natural light				**Natural light**			
Daylight	53.6	44.0	57.7	Lack of/insufficient daylight	61.5	62.5	52.2
Skylight	10.7	24.0	3.8	Skylight	3.8	4.2	4.3
Proximity to window	14.3	12.0	15.4	No window	0.0	4.2	4.3
Outdoor view	25.0	4.0	15.4	**Lack of/ unpleasant outdoor view**	11.5	12.5	13.0
Privacy				**Privacy**			
Privacy	32.1	20.0	11.5	No privacy	7.7	8.3	0.0
Private position	7.1	8.0	0.0	Non-private position	0.0	0.0	4.3
Feeling isolated	0.0	24.0	11.5	Feeling isolated	7.7	8.3	8.7
Desk				**Desk**			
Desk feature	7.1	4.0	15.4	Desk feature	0.0	4.2	13.0
Desk location	3.6	8.0	15.4	Desk location	23.1	12.5	8.7
Indoor conditions	7.1	4.0	3.8	**Indoor conditions**	15.4	12.5	21.7

mention daylight as a reason (174.9±183lx), [t(48)=2.1, $p=0.052$]. It could be explained that daylight availability on a specific desk that meets an occupant's needs and preferences, namely individual daylight expectation, usually influences seat preference. Therefore, daylight availability of the selected desk could be used as an indicator of an individual's daylight preference.

Other Influential Factors

Figure 4 presents the seat preference configuration against the library's daylight availability when the experiment was conducted. The categorisation of lighting levels was done based on the recommended range for library reading rooms (between 300 and 500 lux; Keskin, 2019). It can be seen that most (86%) of the seats selected as the best are located in areas with high illumination, whereas most unpopular desks are located in places with poor or lack of daylight. Interestingly, two desks were regarded as both best and worst by different participants. One of them, located in Room 1, corresponds to an individual cubicle that does not have access to outdoor view or acceptable daylight levels. The desk was selected as the worst seat by a participant because of the deficient daylight level; however, another participant preferred it because the desk was at the corner and more private than others. Another desk, described as both best and worst by five participants, is located near the window and in the corner of Room 2. The desk has a satisfactory level of daylight and outdoor view of greenery, which some participants positively appraised; however, others were negatively affected, given its closeness to an emergency exit and facing the people passing through the circulation route.

Desks in Room 3 under the skylight had a high level of daylight when the study was conducted; however, they were not preferred as expected. The desks near the window in Room 2 were more popular than the desks in other rooms. Six participants stated that they do not feel comfortable in the open-plan layout of Room 3, even though it has excellent daylight levels, especially at some desks. They also mentioned that their screens were visible to other students and that even if it was a silent room, it was easy to get distracted due to facing other people. These findings emphasised that seat preference cannot be examined only in relation to daylight, and it should be investigated together with other components reported in the study such as privacy, outdoor view and quietness.

The role of daylight on seat selection may also vary depending on the context, sample characteristics, and the activities participants are requested to undertake. For instance, this study's results could have been different if the participants were in real need of using the space for their respective studies (e.g., reading and writing for an assignment). In that case, privacy and quietness could have been more important than natural environment components such as temperature, lighting and outdoor view. Therefore, the study design might have affected the participants' natural environmental attention and evaluation of the space and desks. However, although the importance of daylight varies from study to study, it always remains an essential factor for seat selection.

Subjective Ratings

After selecting the best and worst seats, participants were asked to rate the daylight conditions on the work plane at the seat they had selected as the best in the library. Then, the perceived daylight conditions of the participants were evaluated towards daylight availability at the best seat selection using an independent-samples t-test. Although some individuals described the amount of daylight different from actual measurements, it was assumed that the contribution of daylight to horizontal illuminance on the desk had a significant effect on the subjective assessment of daylight, $p=0.002$. The correspondence between subjective ratings

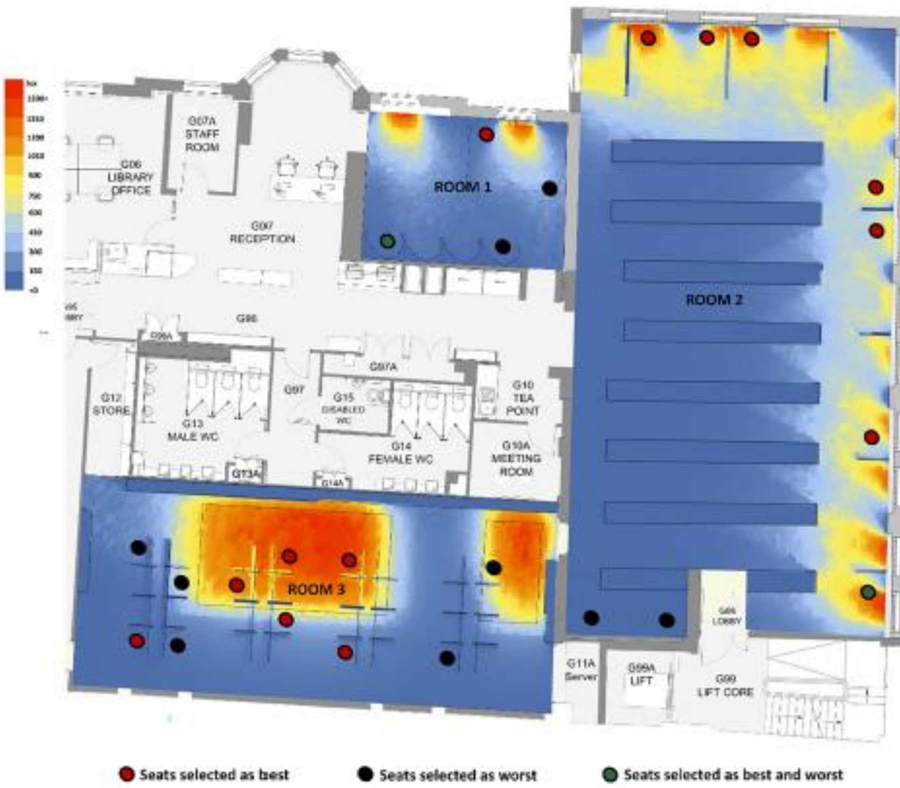

FIGURE 4 | Best and worst seat selected by participants against daylight availability.

and daylight measurements proved that subjective rating is a suitable method for evaluating daylight perception and vice versa. However, even if the difference between the subjective ratings and daylight conditions was minimal, inter-individual differences in perceiving daylight conditions need further investigation.

Daylight Boundary Line

Variation in Perceived Daylight

The library's indoor daylight conditions were assessed by asking participants to draw a boundary line when they noticed a distinction between daylit and non-daylit spaces. A few examples of participants' drawings are shown in **Figure 3**. In this experiment, some participants described the daylight availability in certain areas as very high, whereas others found the daylight in the same areas low or insufficient. The overlapped drawings gathered from all participants are presented in **Figure 5**. Participants' average perceived bright area in the library varied from ~16 to ~100 square meters (mean = 40.3, SD = 24.6, $N = 50$). Perceived daylight conditions varied over an extensive range from person to person regardless of actual daylight measurements. Therefore, aspects that can intervene and cause the discrepancy between actual daylight measurements and participants' perceptions from drawings deserve further attention.

Daylight Availability and the Overall Perception

In order to categorise and visualise the areas agreed by a certain number of participants as bright, the overall perception of daylight composition within each room was evaluated using the statistical quartile concept. Spaces were differentiated as *fully daylit* (perceived as bright by at least 75% of participants), *partially daylit* (perceived as bright by at least 25% of participants), and non-daylit (area perceived as bright by less than 25% of participants; **Figure 6**). Despite the inter-individual differences in the participants' perceived daylight conditions from drawings, there are still apparent areas in the centre of rooms 2 and 3 that all participants agreed to be the dimmest and brightest, respectively.

The participants' overall daylight perception was overlapped with daylight availability in the library to determine the difference between perceived daylight availability from drawings and actual daylight measurements. Handina et al. (Handina et al., 2017) found that the most compatible metric to evaluate boundary line drawings concerning daylight availability in a space is DA300lx,50%.

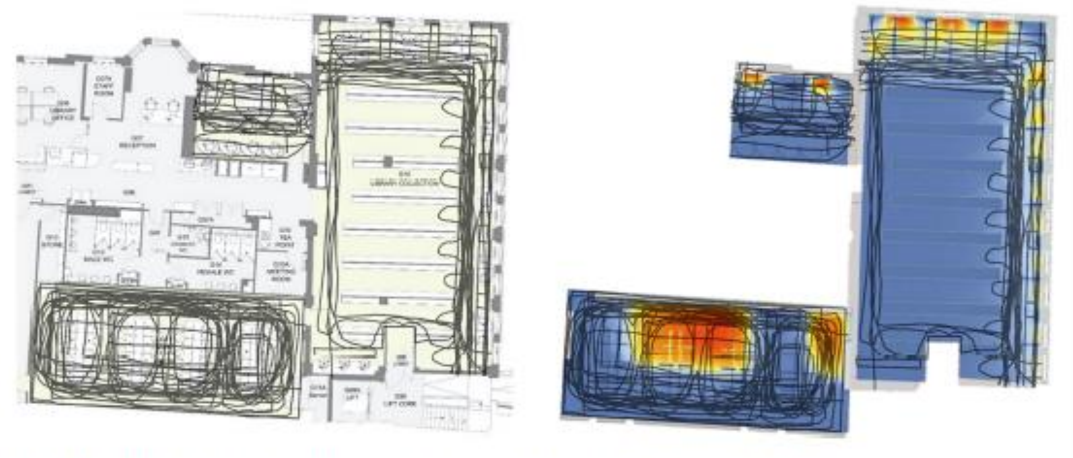

FIGURE 5 | Daylight boundary line drawings of the participants (left). Comparison of drawings with daylight availability (right).

Thus, Daylight Autonomy (300lx,50%) was used to evaluate daylight boundary line drawings as a daylight availability metric that corresponds to 50% of the occupied time when the target illuminance of 300 lux on a horizontal plane is met by daylight.

As seen in **Figure 6**, only in Room 3, the percentage of the area enclosed with the contour line of DA300lx,50% (41.3%) to some extent, corresponds to the partially daylit area (45.1%). However, the percentage of DA300lx,50%, was not close to the other two rooms' fully daylit areas. Therefore, this method could somewhat explain the tendency in daylight perception of a group of people, despite the noticeable inter-individual differences in the daylight boundary line drawings. It could be useful for comparing daylight perception of a particular group of people, such as people's perceptions living in different latitudes. However, space's characteristics such as the room's size, window type and size, and seat configuration could explain the possible difference in participants perception. Also, as seen in **Figure 5**, the degree of agreement in the participants' perceived bright area varied. Even though perceived bright areas varied from person to person in Room 2 and 3, the agreed daylit space was more noticeable. Perceived bright areas in Room 1 varied on a wide range, and there is no agreement in the participants' perception. These findings agree with Handina et al.'s (Handina et al., 2017) work, where a noticeable difference was found in the subjective daylight evaluations between small and large spaces. Overall, these findings indicate that this method could be used to compare the overall daylight perception of a particular group of people; however, it needs further investigation for the individual assessment of subjective daylight.

Initial Findings From the Developed Methodology

This paper aims to review the methods previously used to assess daylight perception and establish a methodology for assessing daylight perception in the context of cultural background. As mentioned in the results section, seating preference and subjective ratings seem as suitable methods for evaluating daylight perception of individuals. Therefore, as a part of cultural background in the lit environment (Izmir Tunahan et al., 2021), the contribution of ethnic background and time spent in a specific environment to the participants' responses was analysed. The results from the seat preference method showed that when selecting the best seats, the leading reason for 48.5% of Asian participants was daylight, followed by privacy (15.2%), quietness (6.1%) and indoor conditions (6.1%). On the other hand, 33.4% of White participants selected their favourite desks considering daylight as a priority. Subjective rating method results also showed that Asian participants described daylight conditions on the best-selected desks as equal or lower than actual measurements. In contrast, White participants described daylight conditions as similar or higher than actual daylight conditions. This finding shows similarity with Lee and Kim's (Lee and Kim, 2007) study, which showed that Asian people felt more comfortable than Caucasians towards high glare levels of luminance.

In terms of time spent in London, study findings showed that participants that had been in London for longer periods gave less weight to daylight while selecting a seat than students that arrived a couple of months before the study. Four students born and grew up in London preferred desks with significantly less daylight than non-Londoners. In parallel with their seating preferences, students who spent more time in London described the daylight conditions at the best desk as more acceptable. Acclimatisation to daylight conditions over time could affect subjective daylight evaluations and explain this finding just as shown by Martin et al. (Hébert et al., 2002). However, participants' daily routine, how long they are exposed to outdoor daylight conditions and in which timeframe also matter in addition to the daylight availability of the city. Together these findings show that there could be an association between cultural

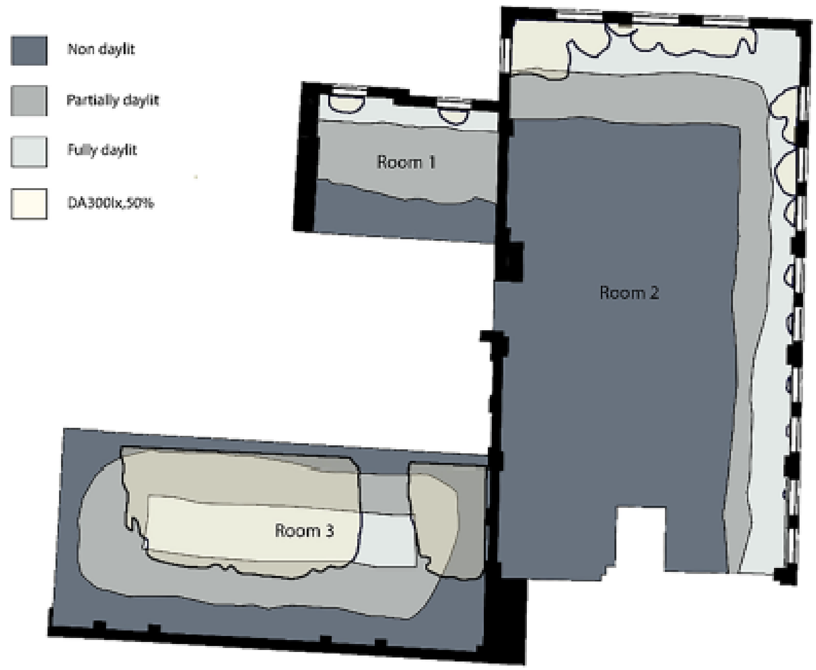

FIGURE 6 | Comparison of the overall daylight perception with percentage of the area enclosed with the contour line of DA300lx,50%.

background and subjective daylight evaluations; however, it needs further investigation with a large sample size of participants considering all cultural background components.

Limitations and Future Work

- The study was limited to a particular place and a particular group of people at a given point in time. The small sample size was another limitation that did not allow to generalise of the findings.
- The role of daylight on seat selection may vary depending on the context, sample characteristics, and the activities participants are requested to undertake. Study results could have been different if the participants were in real need of using the space for their respective studies (e.g., reading and writing for an assignment). In that case, privacy and quietness could have been more important than natural environment components such as temperature, lighting and outdoor view. Therefore, the study design might have affected the participants' natural environmental attention and evaluation of the space and desks.
- Even if the difference between the subjective ratings and daylight conditions was minimal, the reasons for perceiving daylight conditions different from other individuals need further investigation, and inter-individual differences should be examined deeply in further studies.
- The use of drawings to measure participants' perceptions, such as the daylight boundary line method, has some limitations because it involves cognitive and motor processing simultaneously. Therefore, it is suggested (Mitchell et al., 2011) that when a drawing is used as a research method, it should entail participants' drawing and talking, or drawing and writing to interpret the meaning embedded in their drawings.
- The impact of cultural background on daylight perception was evaluated considering only ethnic background and time spent in London. However, cultural background in the lit environment comprises many aspects. Further analysis is needed as suggested by (UKCISA, 2017) considering the luminance environment where people used to live, the luminance environment they were recently exposed to, the socio-cultural background, and individual lifestyle daily routines.

CONCLUSION

Daylighting is an essential component of the indoor environment that can greatly influence the occupants' comfort and wellbeing. For assessing the daylighting quality, photometric measurements on their own do not wholly represent the subjective aspect of the lighting environment; therefore, more attention should be paid to how participants perceive the same daylight conditions and which method can predict the daylight perception of the participants much better. This paper has presented a summary of current methods for assessing daylight perception and established a methodology for assessing daylight perception in the context of cultural background. In lighting studies, culture represents the many aspects from individuals' characteristics and the climatic and indoor conditions people have experienced. Hence, people from different cultural backgrounds might have different expectations of the lit environment. This knowledge could be used to investigate how users interact with the building and develop strategies to reduce unnecessary electricity consumption in addition to the contribution to human health and wellbeing.

This paper showed that subjective ratings, the amount of daylight described by participants, coincide with the daylight availability on specific surfaces. However, there remains a slight difference between participants' statements and actual daylight conditions. The reasons why daylight conditions are perceived differently by participants need further investigation. The findings from the seat preference method showed that daylight was the most dominant reason when selecting the best desks in the library, followed by privacy, outdoor view and quietness, respectively. Although the reasons for seat selection varied, the majority of the participants agreed on particular reasons; satisfactory daylighting level, facing the least people, and a greenery outdoor view. This study also showed that the perceived daylight conditions obtained from the daylight boundary line method varied extensively from person to person regardless of actual daylight measurements. Therefore, aspects that can intervene and cause the discrepancy between actual daylight measurements and participants' drawings deserve further attention. Initial results from the developed method demonstrated that there could be an association between cultural background and subjective daylight evaluations; however, it needs further investigation with a large sample size of participants considering all cultural background components.

Together these findings showed that subjective rating and seat preference methods could be used to evaluate daylight perception. Although daylight availability corresponds better with subjective statements, collecting participants' subjective responses would not always be possible, especially in large-scale studies. Therefore, the combination of subjective rating and seat preference methods is suggested as appropriate methods for assessing daylight perception. Future research should also consider the impact of other environmental parameters on seat preference and how they relate to lighting conditions to improve occupant satisfaction. The interaction between any parameter and seating choice should not be examined in isolation; other aspects, such as privacy, outdoor view and quietness, should also be considered. Inter-individual differences in daylight perception are also worth investigating further.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, and further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the UCL Research Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

GI conducted the research and reported the results. HA (primary Ph.D. supervisor), JU (secondary Ph.D. supervisor), and CT provided feedback. All authors contributed to the article and approved the submitted version.

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APPENDIX 1

Details of the rooms and technical properties of the surfaces.

		Room 1	Room 2	Room 3
Room geometry (m)	Depth	6.50	19.30	15.20
	Width	4.70	10.30	7.00
	Height	2.81	3.75	2.79
Room reflectance*	Floor (carpet)	0.03	0.03	0.03
	Walls	0.85 and 0.24	0.77	0.85
	Ceiling	0.79	0.79	0.79
	Window frame	0.81	0.81	–
Furniture reflectance	Desk	0.64	0.23	0.67
	Territory element	0.06 and 0.10	0.50	0.13
	Bookshelves	–	0.27	–
Opening geometry (m)	Number of openings	2 windows	13 windows	2 skylights
	Height x Width	1.99 × 1.25	2.58 × 1.25 and 2.58 × 1.68	–
	Width x Depth	–	–	3.20 × 6 and 3.20 × 1.80
Glazing characteristics	Visible transmission	0.60	0.60	0.60
Blinds		No	Yes—Occupancy controlled internal blinds	No
Orientation		N	N–E	–
Outdoor view characteristics		Church	Church and back building facade	Only sky view

KONICA MINOLTA Illuminance meter T-10A (20014862) and KONICA MINOLTA Luminance gun meter LS 100 were used to measure surface illuminance and surface luminance, assuming perfectly diffusing surfaces, and this formula "Luminance=Reflectance x Illuminance/π" was applied to calculate reflectance of the surfaces.

Appendix 7.2: A proceedings paper entitled with “The role of daylight on users' seat preferences”

The title of the proceedings paper	The role of daylight on users' seat preferences
Authors	Gizem Izmir Tunahan, Hector Altamirano and Jemima Unwin Teji
Conference	CIE 2021 Conference (International Commission on Illumination) in Malaysia
Date of publication	29/09/2021
Presentation	Oral presentation and publication
Access from	https://doi.org/10.25039/x48.2021.OP24

THE ROLE OF DAYLIGHT ON USERS' SEAT PREFERENCES

Izmir Tunahan G.[1], Altamirano H.[1] and Unwin Teji J.[1]

[1] Institute for Environmental Design and Engineering, University College London, London, United Kingdom

gizem.izmir.tunahan.17@ucl.ac.uk

Abstract

Seating that meets the needs and preferences of students can promote a longer stay in libraries and keep students motivated, which in turn influences their emotions and learning abilities. However, existing knowledge on the interaction between daylighting and seating preferences is limited. This study aims to understand what type of spaces are in more demand and the relationship between seat occupancy and daylight availability. Occupancy data of the UCL Bartlett library acquired from motion sensors located underneath each desk was used to assess occupancy, which was then compared to characteristics of space, including daylight availability. The study revealed that although daylight has a considerable impact on students' seat selection, the seating preference of the students cannot be explained by daylight alone. The seats with a good combination of daylight, outdoor view and privacy are in more demand compared to seats that provide only a high level of daylight. Future research should involve individual perception in addition to occupancy monitoring data, considering daylight conditions together with other components such as privacy, outdoor views, and quietness.

Keywords: Daylight, Seat preference, Occupancy monitoring, Sensors

1 Introduction

The expectation of occupants and their behaviour in the built environment could vary depending on the building type, building design features, climatic conditions, type of activity (Delzendeh et al., 2017), and people's personalities (Nel and Fourie, 2016). Understanding occupants behaviour and their interactions with the indoor environment could provide insights into how to improve occupants' satisfaction (Paone and Bacher, 2018) and the energy efficiency of a building (Andersen, 2009) (Fabi *et al.*, 2012). For instance, understanding the reasons behind selecting a particular seat in an environment could help inform the strategies to improve occupants' satisfaction and maximise the benefit of an environment such as a library that has an essential role in enhancing students' achievements.

The seat selection process results from the individuals' prior experiences in a space or a deliberate choice among alternatives while entering the space (Stone, 2002), regardless of whether deciding consciously or unconsciously (Kahneman, 2011). Seating selection is different for individuals familiar or unfamiliar with a space's physical settings (Keskin, 2019). The human response to the physical environment is strongly subject to prior experiences (Boyce, 2014). For example, library users could repeatedly choose the same seat depending on prior experiences, whereas first-comers need to rely on external sources such as existing lighting conditions, noise level, etc. The availability of seats at a particular time could also influence seat selection; individuals who arrive earlier at the library have more chances to select a seat than those arriving later. Individual differences, namely arousal, motivation, and expectation, also matter in human behaviour (Boyce, 2014), influencing the decision-making process. All these factors considered together could make a difference in individuals' seat preference behaviour.

Linking the seating behaviour of individuals with a particular stimulus in the physical environment is quite difficult because individuals are exposed to multiple sources of information during the seat selection process. The behavioural response to a physical stimulus in an environment is not directly associated with its magnitude, but with the interaction of the people and the environment, they are exposed to (Boyce, 2014). According to Barker et al.(1978), human behaviour in a space could be explained by the physical environment conditions they are exposed to rather than individual characteristics. Barker et al.(1978) proved that human behaviour shows similarity against a set of physical object arrangements (i.e. chairs and desks) regardless of the individual differences.

The factors influencing seating behaviour in the learning environment have been defined in various studies as ambient temperature, type of furniture, proximity to other occupants (Dubois, Demers and Potvin, 2009), quietness, outdoor view, privacy, social interactions such as close to friends, entrance or circulation (Gou, Khoshbakht and Mahdoudi, 2018), daylight (Keskin, Chen and Fotios, 2017) (Othman and Mazli, 2012), students' degree of territoriality and seat arrangements (Kaya and Burgess, 2007). It is also known that when choosing a space, individuals tend to value a few specific variables rather than evaluate each environmental variable equally (Keskin, 2019). For example, the impact of daylight on seating behaviour is also affected by the variations in other factors that influence the decision-making process, and the role of daylight in seat selection remains hidden behind them (Boyce, Hunter and Howlett, 2003). The underlying processes of seating behaviour within a specific physical environment have not been completely understood yet.

The spatial orientation of an individual relies on the interpretation of changing retinal images and the updating of this information whilst walking through a space (Cuttle, 2008). The received visual information with auditory and tactile senses is used to deci de on location, position and movement (Keskin, 2019). Therefore, as a part of the dominant source of sensory information (vision), daylight is regarded as an essential component for the spatial orientation of an individual. It gives individuals a sense of place with the changing intensity and direction of illumination over time (Keskin, 2019) and potentially influences their spatial orientation within an environment (Boyce, 2014) (Dubois, Demers and Potvin, 2009). The luminous environment could impact individuals' decision-making process in remaining at the same location or moving somewhere else. In the case of changing the location and ultimately luminous environment, individuals may develop a sense of awareness of the luminous similarity or contrast (higher or lower amount of illumination) with other spaces. In other words, they put the spaces in luminous order during their seat selection (Flynn, J E; Segil, A W; Steffy, 1988).

The type of task to be also performed matters for the importance of daylight on seat selection. For example, visual tasks that require greater attention, such as reading, may influence individuals to choose particular locations with mostly higher daylight levels (Flynn, J E; Segil, A W; Steffy, 1988) (Steane, 2011). However, in some situations, people may need a place to focus with less awareness of sensory information arising from their external environment (Steane, 2011). For instance, during exam periods, privacy and quietness are more critical aspects for students (Cox, 2018) (Walton, 2006) than daylight levels.

This study aims to investigate the impact of daylight availability on the students' seating selection in order to understand how to improve the students' satisfaction with a space and reduce energy consumption.

2 Methodology

2.1 Field site

The study was carried out in the UCL Bartlett library located on the ground floor of a six-storey building. The library comprises three main study areas (Figure 1) with different layouts and lighting designs. Room 1 has eight shared desks and four individual cubicles, Room 2 has twelve shared desks and eleven individual desks, and Room 3 has thirty-two shared desks. In terms of daylight, Room 1 has two north-facing side windows, and Room 2 has several side windows facing north and east orientations. Room 3 is an open plan space with two skylights.

Figure 1 – Plan of the Bartlett Library

2.2 Occupancy monitoring

The utilization of seats in each UCL library has been monitored and recorded on a 10-minute basis since 2017 (UCL, 2017). The purpose of monitoring the occupancy of 4,000 seats is to provide students with real-time availability of the study space via an app called UCL Go!. The app aims to help students save time, enabling them to choose an adequate study space according to their needs and expectations, which in turn will have a considerable impact on students' academic performance (Will, Bischof and Kingstone, 2020).

Occupancy data was obtained from PIR sensor boxes (infra-red technology) attached to the base of each desk that detect if the desk is available. The information regarding whether the particular desk is occupied at a specific time is sent to OccupEye Cloud and is plotted using a range of red and green colours that indicate for what percentage (%) the desks have been occupied (Figure 2). This study has analysed data recorded from the Bartlett Library between 2018 and 2019.

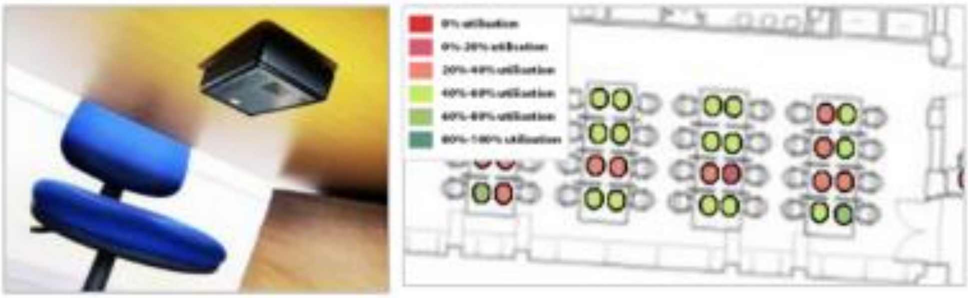

Figure 2 – PIR sensor boxes (left)
Representation of occupancy at each seat in Occupeye Cloud (right)

2.3 Quantification of daylight availability

In order to analyse the role of daylight availability on seating selection, AutoCAD and Rhino were used to produce 2D and 3D drawings of the library. Then, Grasshopper was used to create lighting performance analysis for the parametric modelling with Ladybug and Honeybee plugins.

Spot illuminance measurements were taken using a KONICA MINOLTA illuminance meter and luminance gun meter. The measurements were used to calibrate the developed model.

2.4 Procedure and methods of analysis

The data obtained from the UCL library occupancy monitoring system was analysed to understand what type of spaces were most in demand in the library and the role of daylight on seating selection. The data used in the analysis considered the utilisation of desks between 9:00 and 20:00 on weekdays and between 11:00 and 18:00 on Saturdays, between the 1st of January 2018 and 1st of January 2019. The data were analysed in the following ways:

- ***The desks/ rooms in most and least demand:*** The annual occupancy of each desk was analysed to investigate the desks and rooms with the most and least demand, hence, the popularity of the desk and its relationship with daylight availability.

- ***Order of preference of desks:*** The degree of freedom of choice could influence the seating decision because individuals can choose only available seats. For instance, they could have more chances to select desks early in the morning than those who arrive in the afternoon. Thus, the selection of desks in the morning hours was analysed.

  The analysis was conducted for weekdays from 9:00 to 12:00 at 30 min intervals. The seating pattern on a typical day was defined considering the percentage of the time a desk was occupied between 9:00 and 12:00 for an entire year (Table 1). If a desk was occupied at equal or more than 90% of the time, then that desk was regarded as occupied (Figure 7).

DESK 1	9:00-9:30	9:30-10:00	10:00-10:30	10:30-11:00	11:00-11:30	11:30-12:00
01.01.2018	1	1	1	1	0	1
02.01.2018	1	0	1	0	1	0
03.01.2018	0	0	0	1	0	1
04.01.2018	1	1	1	1	0	1
⋮	⋮	⋮	⋮	⋮	⋮	⋮
31.12.2018	1	0	1	1	0	0
The utilization of Desk 1 on a typical day	The percentage of occupied cases/ Total cases	The percentage of occupied cases/ Total cases	The percentage of occupied cases/ Total cases	The percentage of occupied cases/ Total cases	The percentage of occupied cases/ Total cases	The percentage of occupied cases/ Total cases

Table 1 – Method of analysis for the occupancy of each desk at a specific time interval
(1: occupied, 0: unoccupied)

- ***Length of stay at the same desk:*** This method aims to understand how long a desk was utilised without interruption or becoming vacant on a typical day. The analysis was conducted for weekdays from 12:00 to 20:00 with an hour interval. The seating pattern on a typical day was defined considering the percentage of the time a desk was occupied between 12:00 and 20:00 for an entire year. If a desk was occupied at equal or more than 90% of the time, then that desk was regarded as occupied.

3 Results and Discussion

As seen in Figure 4, the library reaches maximum occupancy in Springtime (March, April, May), whereas there is not much demand in Summer. April and September are the most and least busy times of the library, respectively. Mondays seem to be the busiest days, while Saturdays are the quietest. On a weekday, the library reaches the first peak occupied time at around midday and then the second one at around 15:50. In contrast, the busiest time in a day is around 15:30 at the weekend (Figure 4)

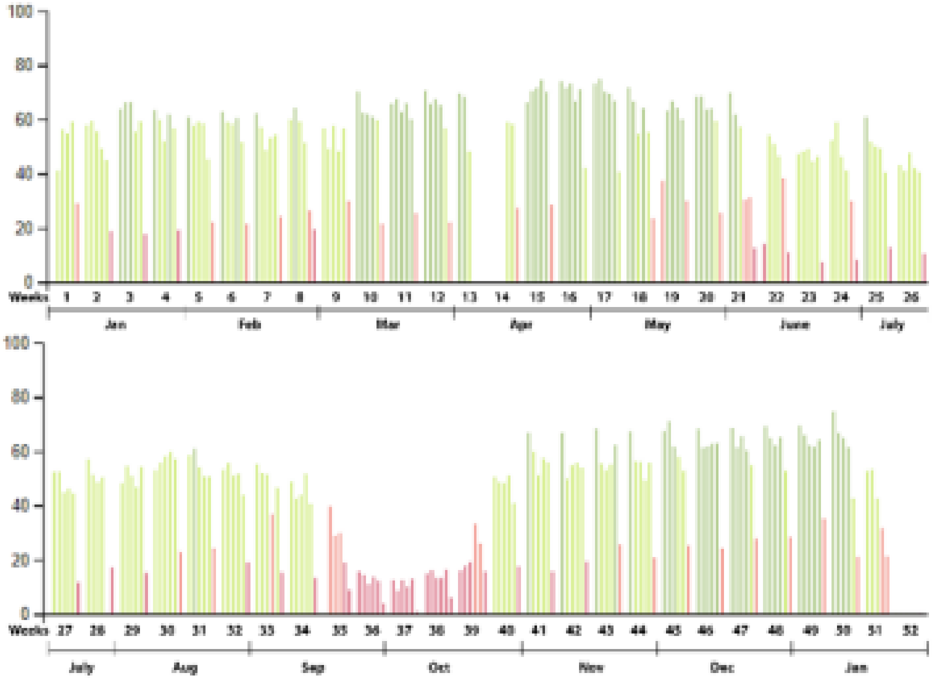

Figure 3 – Occupancy of the Bartlett Library (Jan 2018 to Jan 2019)

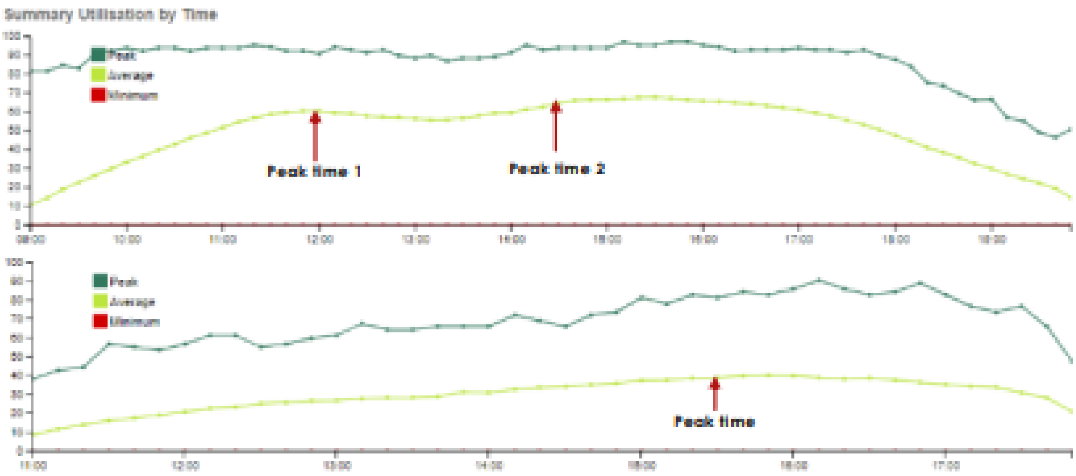

Figure 4 – Daytime occupancy during weekdays (top) and weekend (bottom)

3.1 The desks in most and least demand

Figure 5 shows that the most preferred desks are located in Room 2, which has access to daylight and an outdoor view. In this room, the individual desks were in higher demand than shared desks. Desk 32, an individual desk with both daylight and outdoor views, is the desk with the highest demand. The least utilised desk is Desk 35; it lacks access to daylight and outdoor view and privacy as it is located close to the circulation between Room 2 and 3.
The desks in Room 2 were positively appraised by most participants even though they have lower daylight levels than the desks under the skylights in Room 3. This preference could be explained due to the absence of an outdoor view of Room 3 and its open-plan layout, hence the lack of privacy.

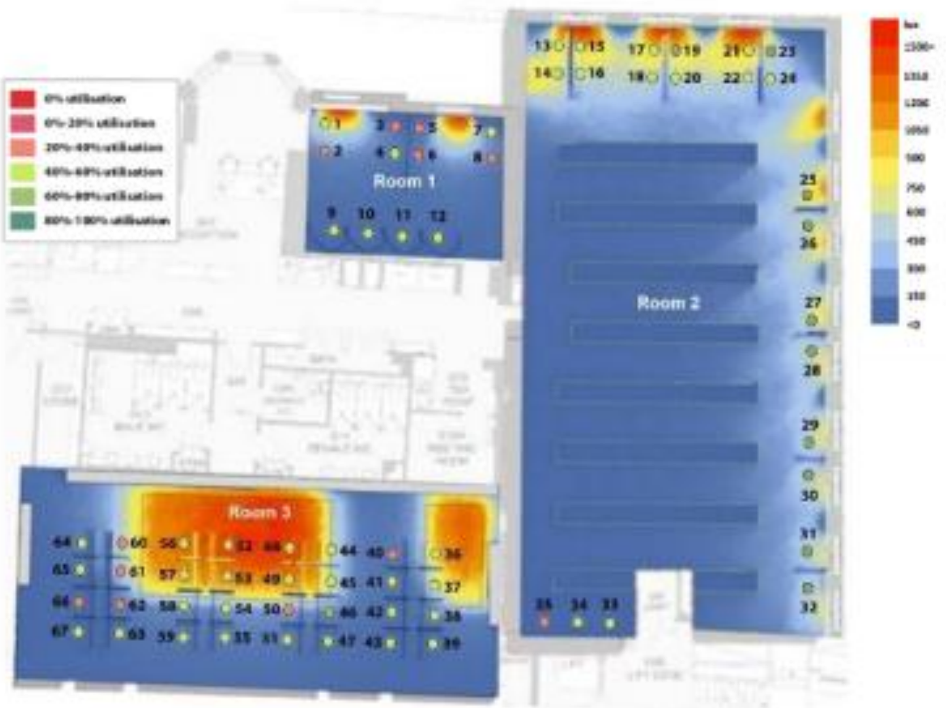

Figure 5 – Utilisation level of each desk and daylight availability

3.2 The rooms in most and least demand

As previously stated, Room 1 and Room 2 have several side windows allowing the students to have desks with access to daylight and outdoor views in contrast to Room 3, illuminated by skylights without access to outdoor views but with high daylight levels, especially at some desks. As seen in Figure 6a, desks with higher daylight on the horizontal plane and illuminated by side windows are those with higher utilisation. The highest utilization belongs to desks near a window followed by desks with access to outdoor view and less daylight. The least utilized desks are desks with no outdoor view and the least daylight. Although daylight does not seem to affect the utilization of desks lit by the skylights in Room 3 (Figure 6b), desks under the skylight still show the highest utilisation. It can be concluded that daylight promotes seat selection in places daylit by the side windows; however, the importance of daylight on seat selection under the skylight is minimal.

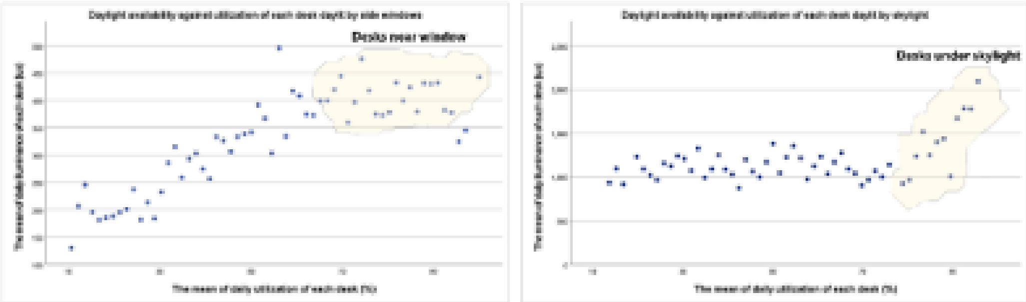

Figure 6 – Daily illuminance against daily utilization of each desk lit by side windows (a) and skylights (b)

Access to outdoor views and acceptable daylight levels make certain seats more preferable than seats with only adequate daylight levels, such as those in Room 3. Privacy could also be affecting the selection of seats in Room 3 (open plan). These findings emphasise that although daylight is one of the most important factors for seat selection, seat preference cannot be explained by daylight alone. It should be investigated together with other components such as privacy, outdoor views, and quietness.

3.3 Order of preference of the desks on a typical day

Figure 7 presents the association between the order of preference for the desks between 9:00 and 12:00. As seen, first comers to the library mostly prefer the individual desks in Room 2. These desks mostly have a good combination of daylight, outdoor view and privacy, but they are not necessarily the ones with the highest daylight availability. Following, students seem to prefer the shared desks in Room 2 with an outdoor view and comparatively less daylight availability and less privacy. After the desks in Room 2 are fully occupied (between 10:00-10:30), students select desks in other rooms, mostly with the highest daylight levels initially. After all, desks getting a high amount of daylight in Room 3 are fully occupied, students begin to select the other desks in the same room with the lack or insufficient daylight levels. These desks are mostly with the least daylight availability with no privacy and no outdoor view. Corner desks were more preferable in this period because they are comparatively more private. Although some desks in Room 1 have access to daylight and outdoor view like Room 2, some of them are not preferred by students. It could be explained that Room 1 has a North orientation and is comparatively darker than Room 1, especially in the early morning hours. These findings show that a high amount of daylight promotes people to select particular places; however, the role of daylight should be considered with the combination of other factors.

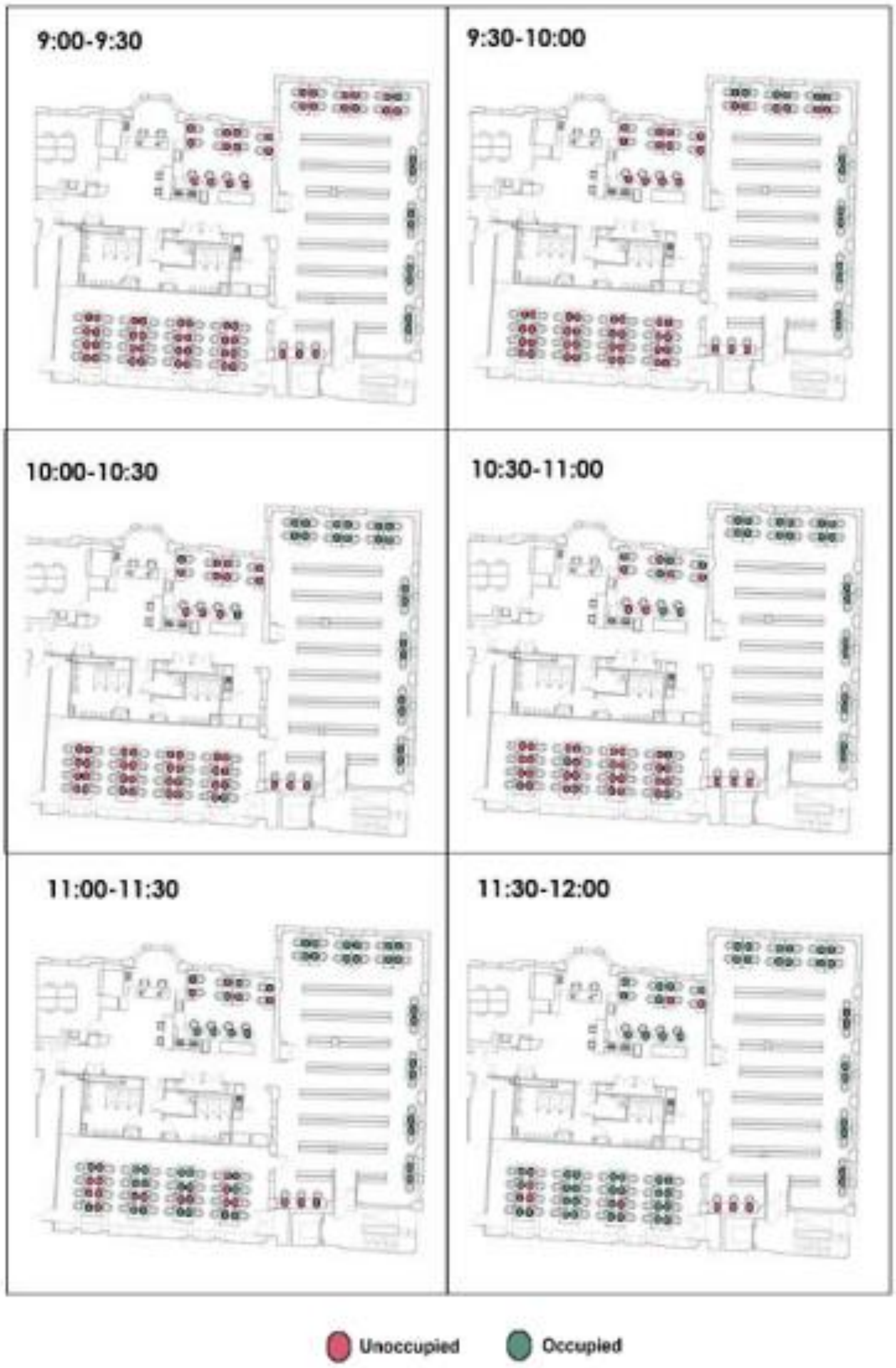

Figure 7 – Seating preference of the students in the early hours on a typical day

3.4 Length of stay at a desk

In terms of length of stay at the same desk, as seen in Figure 9, the desks in Room 2 are utilised most of the day without interruption or becoming vacant. However, desks in Room 1 and 3 seem to be used for shorter periods, especially after 17:00. As supported by previous findings, individual desks in Room 2 were continuously used, followed by shared desks in the same room. The desks in Room 3 used for longer periods were mainly those located under the skylights and those located in the corners despite the lack or insufficient daylight levels. Interestingly, individual cubicles in Room 1 showed a continuous utilization against shared desks in the same room despite the access to outdoor view and daylight availability.

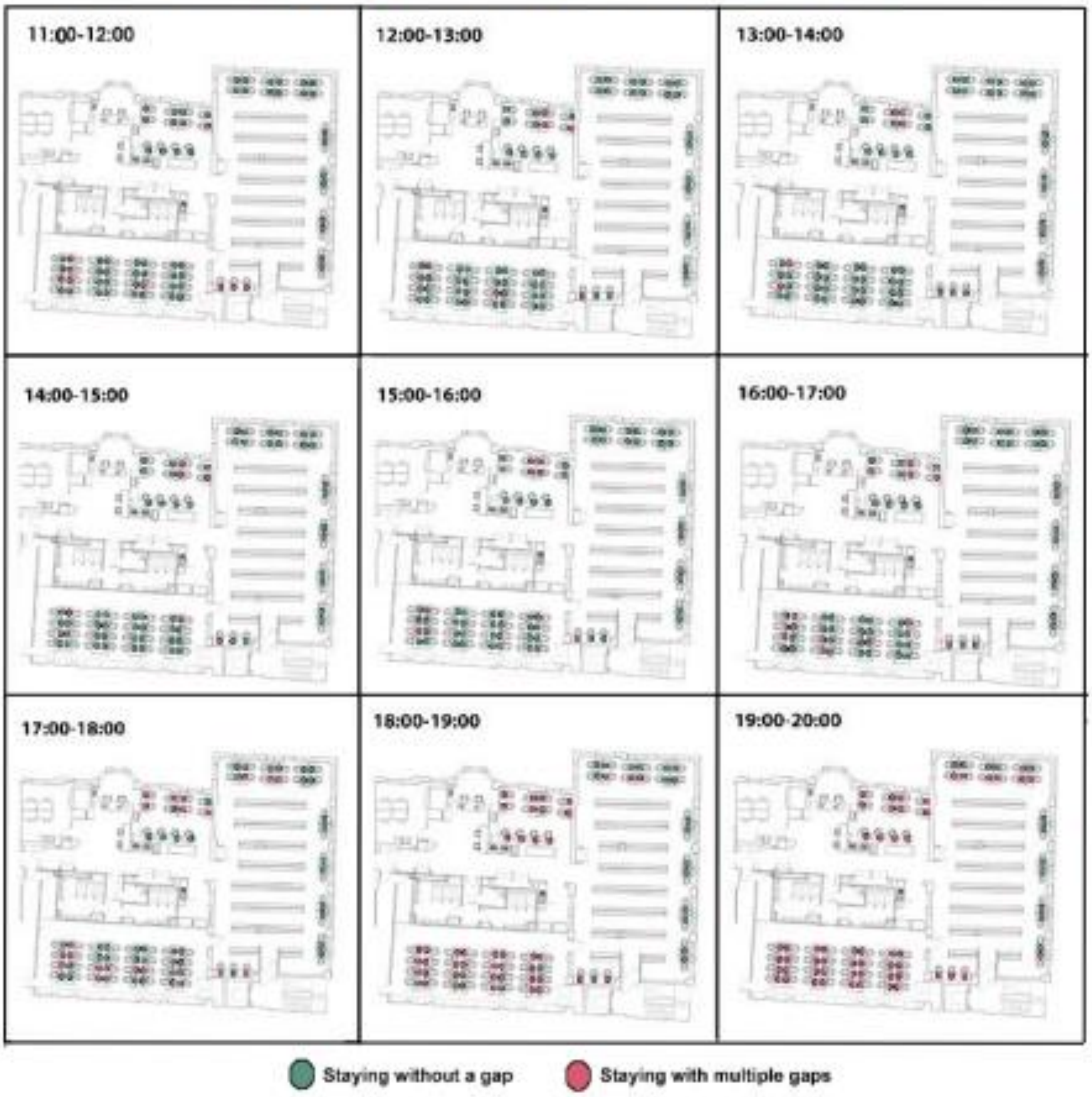

Figure 9 – Length of stay at a desk on a typical day

3.5 Limitations

Although the data collected through the sensors indicate whether the space is in use or available, demonstrating which desks are most preferred, these devices do not collect any personal data and cannot identify an individual. Therefore, study results do not represent students' personalities, individual perceptions and expectations. Another limitation is that students occasionally leave their laptops, water bottles, and backpacks to claim a seat while they go outside. PIR sensors can not detect a claimed seat due to no large heat signatures or movement. This situation could affect the students' freedom of choice and ultimately study findings because it assumes that it is available for selection if a desk seems unoccupied.

4 Conclusion

This paper describes a method that uses seat preference to understand what people choose to do in a space. Data obtained from the UCL library occupancy monitoring system was analysed to understand what type of desks were more in demand during 2018 and 2019. Then, the utilisation of the desks was evaluated specifically using daylight availability to explore the role of daylight on human seating behaviour. This study considered the seating preference of the students in terms of the frequency of selecting a specific desk, its order of preference and length of stay at the same desk.

Most of the seats selected as the best were located in areas with high illumination. However, the seats with a good combination of daylight, outdoor view, and privacy were more demanded than the seats providing only a high level of daylight. The study findings also demonstrated that the increase in the illumination of the desks is generally followed by higher utilisation in places daylit by the side windows rather than skylights. It could be argued that access to outdoor views and acceptable daylight levels makes the seating places more preferable than only daylight. Privacy seems to be another critical component because the area lit by skylight is an open plan space and comparatively less private than other rooms.

These findings emphasised that although daylight has a considerable impact on students' seat selection, the seating preference of the students cannot be explained by daylight alone. Future research should consider daylight factor together with other components such as privacy, outdoor views, and quietness, and it should also involve exploration of how people perceive space.

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Appendix 7.3: A proceedings paper entitled with "Conceptual Framework of Cultural Background in the Lit Environment"

The title of the proceedings paper	Conceptual Framework of Cultural Background in the Lit Environment
Authors	Gizem Izmir Tunahan, Hector Altamirano and Jemima Unwin Teji
Conference	CIE 2021 Conference (International Commission on Illumination) in Malaysia
Date of publication	29/09/2021
Presentation	Oral presentation and publication
Access from	https://doi.org/10.25039/x48.2021.OP63

CONCEPTUAL FRAMEWORK OF CULTURAL BACKGROUND IN THE LIT ENVIRONMENT

Izmir Tunahan G.[1], Altamirano H.[1] and Unwin Teji J. [1]

[1] Institute for Environmental Design and Engineering, University College London, London, United Kingdom

gizem.izmir.tunahan.17@ucl.ac.uk

Abstract

In environmental terms, culture represents the climatic and indoor conditions people have experienced during a significant part of their life. Consequently, people exposed to different cultures might have different expectations of the lighting environment. Knowing the lighting expectations due to cultural experiences have numerous advantages; it could help meet the occupants' needs and preferences and provide occupant satisfaction, reducing unnecessary energy consumption in the built environment. This paper aims to summarise a systematic review to create a conceptual framework of cultural background in the lit environment, which could help understand the impact of cultural background on daylight perception and expectation. This review highlighted that cultural background in lighting environment should be evaluated considering **(1)** the ethnicity and/or physiological characteristics of the individual eyes, **(2)** the area (luminance environment) where people used to live **(3)** the luminance environment they were recently exposed to and **(4)** the socio-cultural background of individuals. Future research should further test these components together and separately to investigate which component or combination is more influential on daylight perception.

Keywords: *Daylight, Cultural background, Daylight perception, Residential area.*

1 Introduction

'Culture' is a broad subject, and generally accepted use of culture refers to people's general customs and beliefs. However, Pierson, Wienold and Bodart (2018) have put forward a new definition of culture as "the climatic and indoor conditions which people experienced during their major part of life." As a result of the cultural experiences, human behaviours toward the environment and its expectations are shaped. Consequently, people exposed to different cultures might have different expectations of the lighting environment. Lighting research to date has focused on the impact of cultural background on glare discomfort perception rather than daylight perception and satisfaction (Pierson, Wienold and Bodart, 2018). Also, researchers' approaches to the cultural background concept vary. The cultural components are defined differently because the cultural background concept in the lighting environment has not been comprehensively described yet. Knowing people's lighting expectations due to cultural experiences have numerous advantages; it could help meet the occupants' needs and preferences and provide occupant satisfaction, which in turn help reduce unnecessary energy consumption in the built environment.

This paper discusses the association between cultural background and daylight perception, expectation, and satisfaction. The paper presents and discusses a systematic review to create a conceptual framework of cultural background in the lit environment, which could help understand the impact of cultural background on daylight perception and expectation.

2 Methodology

2.1 Framing questions for a review

The systematic review is reported following the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) Checklist (Moher et al., 2010). Published studies in this field consist of various quantitative and qualitative studies, designed as correlational, cross-sectional, longitudinal, or retrospective, often with specific contexts and small sample sizes. Thus, the range of the reviewed study methodologies includes environments that are analogous in some ways to the situations that people will encounter.

Inclusion and exclusion criteria

The inclusion criteria were: **(a)** including at least one aspect of (day)lighting perception, **(b)** published in English, peer-reviewed journals excluding conference proceedings and books, and **(c)** published during any year from 1990 to November 2019. Scopus, Web of Science, and LEUKOS were searched for electronic records using the following keywords and Boolean search terms. Boolean operators are utilised by defining the main research question's keywords and their synonyms. They make the search more accessible by using AND to combine the keywords, OR to broaden and NOT to eliminate. The Boolean search was done in this way: The keywords in Group 1 (**Culture*** OR "**Prior light history**" OR "**Previous light history**" ..) **AND** the keywords in Group 2 (**"Daylight perception"** OR **"Light perception"** OR "**Daylight expectation**"...)

The potentially relevant articles and papers were identified by defining keywords (Table 1) which were searched within each database using the combination of the keywords from Group 1 and Group 2 (Boolean search terms). The search was done in either title, abstract, or keywords of the papers in the Scopus and Web of Science databases. Keywords were searched anywhere in the high-quality Light and Lighting database (LEUKOS) because the database did not allow to search in abstract or title. After downloading the papers from LEUKOS, they were eliminated manually so that they met the identified criteria.

Table 1 – Used keywords in the systematic review

Databases	Group 1: Intervention	Group 2: Outcome
Scopus In Article title, Abstract or Keyword **Web of Science** In Article title, Abstract or Keyword **LEUKOS** In anywhere, then manually checked if it applies to criteria	**Culture** Prior/Previous light history **Prior/ Previous luminous environment** Previous climatic conditions **Daylight experience** Luminance history **Long term light experience** Past daylight experience **Local illuminance** Country of origin **Latitude** Immigrant **Sociocultural** Vitamin D	**(Day)light perception** (Day)light expectation **(Day)light satisfaction** User expectations **(Day)lighting sensitivity** (Day)lighting tolerance **(Day)light adaptation** Visual comfort **Discomfort glare**

2.2 Identifying relevant work

In the first stage of the screening phase, the titles and abstracts of the journal articles were reviewed and manually excluded if they did not meet the criteria mentioned above. The second stage was the assessment of the full-text articles for eligibility based on the method outlined in PRISMA. The results of the eligible studies were exported to Mendeley, which identified 1189 published research articles. Then the duplicates were removed (n=28). Next, if the title or abstract did not provide appropriate information or meet the selection criteria, they were removed (n=1126). These papers mostly involved Biology and Photobiology studies on animals, especially rats and some phytoplankton cells. The considered only included those where the association between cultural background and daylight perception (insufficiency (quantity) and inefficiency (quality)), including daylight adequacy and discomfort glare, were assessed.

Then the remaining full-text articles (n=35) were assessed for eligibility, of which 27 papers were excluded from further inclusion as they were deemed irrelevant (e.g., circadian rhythm studies). Finally, the exclusion resulted in eight relevant journal papers that were analysed further for method and content (Appendix 1). Figure 1 shows the process of inclusion of reviewed papers. In addition to the database search, a manual search of all references cited was conducted in relevant articles. This process led to the identification of 39 published articles of potential relevance. These articles were then considered for inclusion in the systematic review according to the inclusion and exclusion criteria described below.

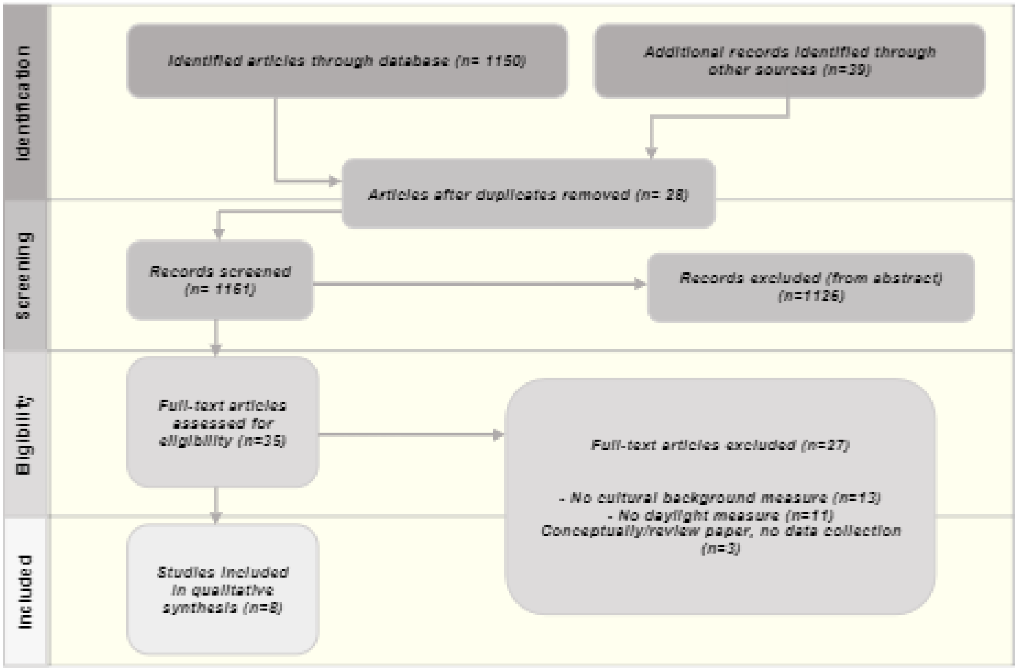

Figure 1 – Flow of information through the different phases of the systematic review
The number of studies included in the qualitative synthesis (N=8)

3 Results and discussion

The selected published articles (Appendix 1) were analysed according to their approach to cultural background. Even though all studies focused on the association between cultural background and daylight perception, they all understand and define "culture" differently. The definitions given to cultural background refer to ethnicity and genetic origin, geographic location of residence, previous luminous environment, and sociocultural context.

3.1 Ethnicity and genetic origin approach

Up to now, various criteria have been used to assess ethnicity (e.g., country of birth, nationality, skin colour, national/geographical origin, and religion and language spoken at home (Office for National Statistics, 2018). However, it has not been described using only one criterion, but a combination of them. In the lighting environment, the ethnic background has been found to affect light perception, specifically discomfort glare perception, assessed through discomfort glare indices. These indices were developed to compare subjects from different studies and to account for differences in the visual properties of particular groups. Indices such as the DGI for British subjects (Hopkinson, 1971), PGSV for Japanese subjects (Tokura, Iwata and Shukuya, 1996), and DGP for German and Danish subjects (Wienold and Christoffersen, 2006) were designed for specific groups and, therefore, their thresholds and the interpretation of findings differ from each other.

Several researchers have assessed subjects from different locations and their discomfort glare perception. For instance, Subova et al. (1991) highlighted the difference in the subjective responses to discomfort glare between subjects in Slovakia and subjects from a similar study conducted in the USA by MacGowan et al. (1988). Furthermore, IWATA et al. (1992) studied the difference in discomfort glare sensitivity between Japanese and British subjects. They found that Japanese subjects were less sensitive to higher levels of discomfort glare than British subjects; although, the compared study procedures were not completely the same. In contrast, Pulpitlova and Detkova (1993) found similar discomfort glare level evaluations from Slovakian subjects compared to American subjects (MacGowan and Emery 1986) by using Hopkinson's discomfort glare scale. Thus, some researchers found either similarities or differences between discomfort glare perception of people from different ethnicities. It may be the result of the application of different indices and study designs.

Lee and Kim (2007) found that Caucasians felt more discomfort glare at high luminance (15,000 lux) than Asians. However, they ignored participants' area of residence and prior light history and assumed that participants living in the same locations have the same ethnic background. A glare perception study done by Kent et al. (2016) could not find any correlation between ethnicity and subjects' glare assessments. However, they found a significant difference in discomfort glare perception of people from different ethnicities in their further studies.

These studies show that ethnicity may be a critical factor leading to how lighting conditions are perceived. Nevertheless, subjects with different ethnic backgrounds may have similar discomfort glare perceptions as long as they lived in the same province and got used to living under those conditions. Therefore, which location participants were selected from, in other words, study design has great importance in interpreting the findings. All of this shows that ethnicity alone cannot be used to predict discomfort glare perception of subjects. For this reason, researchers began to study the properties and visual characteristics of subjects' eyes.

Van den Berg et al. (1991) investigated the optical characteristics and iris colour of Caucasians and Asians and found a variation in light acceptance, resulting in different pigmentation densities between subjects' eyes. Also, Lee and Kim (2007) supported the previous study by showing that Caucasians have less tolerance to high glare levels than Asians due to the physiological properties of the eyes. A remarkable difference was also found between suppressing the production of the hormone melatonin in light-eyed Caucasians and that in dark-eyed Asians (Higuchi et al., 2007). This study demonstrated that the difference in light-based melatonin suppression is associated with eye pigmentation and/or ethnicity.

Many studies have demonstrated differences in daylight perception and preferences resulting from ethnicity and/or individual eyes' physiological properties. However, most cross-cultural lighting studies examined discomfort glare perception and colour temperature preference, but they did not sufficiently focus on the adequacy of illuminance levels. Nonetheless, Belcher (1985) argued that understanding cross-cultural illumination preferences are critical since it can affect feelings of well-being and worker productivity.

3.2 The geographic location of residence

Many researchers have shown that subjective lighting assessments of the same environment are not often consistent. This might result from the acclimatisation of individuals to specific outdoor daylight conditions. For instance, residents in Tel Aviv, where illuminance levels are above 75,000-lux for around 66% of the time, may not have the same daylight expectation as people living in Berlin, where similar levels of illuminance barely occur. Hence, external illuminance conditions might have significant effect on daylight perception, preference, and expectation. However, the amount of exposed daylight also matters in addition to outdoor illuminance levels. Hence, the development of a universal index is difficult due to the distinct cultural differences in illuminance preferences (Belcher, 1985).

Pierson, Wienold and Bodart (2018) proposed that even if the subjects had different ethnical backgrounds, their lighting perceptions were similar because they had been accustomed to the same climatic and environmental conditions resulting from living in the same place. Kim and Mansfield (2016) noticed a cultural difference in the appraisal path between people living in the UK and South Korea. Similarly, Saraiva et al. (2018) found several similarities in climate conditions between students from two different cities in Portugal and Brazil. 80% of the students in Brazil and 78% in Portugal stated that they were satisfied with the indoor lighting environment in their classroom. Despite these two cities' cultural diversity and location, the students' comfort levels seemed comparable, probably due to similar climate conditions they were accustomed to.

Another comparative study between Korean and American subjects showed that Korean immigrants into the US expressed their discomfort with local conditions and how challenging it was to accustom to such different lighting conditions (Lee, 2007). Likewise, some researchers found a noticeable difference in the lighting perception of people living at different latitudes or altitudes. A comprehensive study conducted by Subova et al. (1991) found that subjects in Middle Europe, living around 30 degrees, might have higher sensitivity because of their adaptability to lower luminance conditions. Brandl and Lachenmayr (1994) also showed that altitude change causes some physiological alteration in the human body, and the participants in their experiment indicated different light sensitivity at different altitudes.

Acclimatisation to outdoor daylight levels might affect subjective evaluations of artificial light as well as daylight. A cross-cultural study was conducted by Bodrogi et al. (2017) about the preference for perceived illumination chromaticity among Chinese and European observers. In the study, participants were divided into Chinese and European origin, living in Germany and China. Interestingly, they found similarities in participants' lighting preferences varied depending on where they live instead of their ethnic backgrounds. Another comprehensive field study was conducted to better understand the customers' lighting satisfaction in eight shopping malls across China at four locations (Shanghai, Nanjing, Langfang, and Harbin) with various climatic, economic, and cultural characteristics (Jin et al., 2017). This study found a strong association between the presence of daylight and occupant satisfaction ($p < 0.05$). It shows that people tend to be more satisfied with the conditions they are accustomed to.

Taken together, all these studies demonstrate that people living in the same place and getting used to experiencing under those conditions tend to have similar lighting preferences. However, these studies only considered the lighting conditions that the participants were exposed to and did not involve individual differences resulting from the climatic and cultural diversity of the locations such as ethnic background, lifestyle (how much daylight the individual exposed in a typical day), and sociocultural norms.

3.3 Previous luminous environment

The term "Zeitgeber" is used as a time giver or synchroniser in the field of chronobiology. It is considered as an external cue that synchronises an organism's biological rhythms to the Earth's 24-hour light and dark cycle. The circadian clock features prominently in coordinating biochemical, physiological, and behavioural processes; thus, zeitgebers are vital in human biological rhythms. There are two types of zeitgebers: photic and non-photic, and these components are light, atmospheric conditions, medication, temperature, social interactions, exercise, and eating/drinking patterns. Even though each of these components is linked to each other, lighting takes the lead as the most potent cue to synchronise the circadian clock (Chellappa et al., 2014).

Lighting is perceived only from the retina with the aid of different types of photoreceptors: rods, cones, and recently discovered ipRGCs. Several pieces of research showed that rods and cones play a crucial role in the image-forming vision, whereas the ipRGCs are responsible for the non-image-forming vision. This non-image forming photoreceptive system takes part in the regulation of several functions. However, the impact of lighting depends on the intensity, duration, wavelength, and timing of light exposure (Chellappa, Gordijn and Cajochen, 2011). Nevertheless, there has been very little research directly investigating the effect of the previous luminous environment and its consequent outcomes (Smith, Schoen and Czeisler, 2004).

The previous luminous environment represents the lighting conditions a subject experienced in a specific period. This period may vary from hours and days to weeks and years. Previous studies primarily defined prior photic history as the intensity and duration of prior light exposure. They also demonstrated that the amount of exposed daylight while spending time outside or sitting indoors by a window is significant because prior lighting conditions determine how much melatonin suppressing response to daylight and, ultimately, how we perceive and evaluate lighting conditions. For instance, an individual who spends time outside most of the day may not evaluate daylight conditions as the same as another person who generally spends time indoors even if they live in the same place under the same outdoor illuminance conditions.

Few studies have shown that long-term exposure to low light levels might cause higher sensitivity in the rods and may increase the time of light adaptation (Spitschan, 2019). Besides, a study conducted by Chang, Scheer and Czeisler (2011) indicated that exposure to a very dim light level caused significantly more phase shifting response (60-70%) rather than a typical room light level exposure. Also, long term daylight deprivation has a remarkable impact on participants' sleep-wake patterns and retinal sensitivity after seven months without sunlight ($p<0.05$) (Kawasaki et al., 2018). This view was supported by Martin et al. (2002), who showed that subjects would become less sensitive to light after a week of increased daytime bright-light exposure and that if they are restricted to the dimmer light, they would become more sensitive. The researchers proved significantly more melatonin suppression after a week of exposure to relatively dim light compared with after a week of exposure to long durations (about 4 hr per day) of brighter light. In addition to this, they found higher light sensitivity after the dim week when compared with the bright week. Likewise, in Kawasaki et al. (2018), the exposure time period was extended to seven months to test whether retinal sensitivity, sleep, and circadian rest-activity cycle change during long-term daylight deprivation. They evaluated participants' retinal sensitivity changes towards different lighting stimuli and measured the rest-activity cycle using activity watches. They found an increase in retinal sensitivity to blue light, whereas a decrease in circadian rhythm stability and delay of sleep-wake timing during long-term daylight deprivation.

These studies have shown that the issue of prior light history needs considerable attention as much as other approaches, and prior light history arising from the previous luminous environment has an essential impact on light perception as well as sleep-wake patterns, mood, and cognition.

The study design also matters in the interpretation of the findings because most studies in the literature have limited observation time (mostly a week). However, the amount of daylight exposed for a short period of time may not change the participants' lighting evaluations. For instance, if an individual generally spending time indoors is exposed to high daylight conditions for a week, his internal clock may not be affected (it takes some time to adjust), and his lighting perception may be the same as previous regardless of the exposure time and the outdoor illuminance conditions in the last week. Therefore, prior light history should be considered under (1) the combination of outdoor daylight availability and (2) the subject's lifestyle and preferences for (3) a sufficient time.

3.4 Sociocultural context

As mentioned earlier, the subjective assessment of the same lighting conditions differs from person to person. This variation might be based on socio-cultural context, and ultimately values, customs, and traditions rather than acclimatisation to some kinds of lighting conditions. Individuals who share the same socio-cultural background might judge the conditions similarly or have identical behaviour patterns. Hence, they may have common attitudes and perceptions towards daylight conditions.

Siu-Yu Lau, Gou and Li (2010) tested whether daylight helps to increase the satisfaction of residential buildings in Hong Kong. In contrast to other researchers, they assessed human-window interaction in terms of cultural norms. The study results showed that daylighting was not a dominant factor for residents in domestic window design in Hong Kong, but other factors such as dining habits, views from the living room, and privacy for the bedroom were proved to be more important in the users' perception because of socio-cultural context. Therefore, in some cultures, lighting conditions may not be a primary factor because of the socio-cultural context and lifestyle, so their perception and expectations vary from people living in another cultural background.

Lee (2007) confirmed that Korean temporary residents in the United States found it difficult to accustom to interior lighting conditions. This could be linked to their socio-cultural background and traditions because Koreans value a south-facing house with high daylight illumination levels (Hong, 1975). Similarly, Park, Pae and Meneely (2010) found that Koreans preferred high-intensity light differently from Americans. Koreans also stated that bright lighting arouses them than dim lighting in contrast to Americans. Furthermore, Quellman and Boyce (2002) studied light source colour preferences of European, Asian, Indian, African, and North American people, classifying them depending on skin tones. Their results showed a noticeable between cultural backgrounds. Europeans with the lightest skin type preferred warm light sources, and Asians generally chose light sources with a white colour temperature because whiteness symbolises health in their culture. These studies showed that Korean people specifically value high-intensity lighting, brightness, and white colour temperature. Besides, even though these studies were conducted in various locations, Korean people's judgements were similar regardless of their geographic location of residence and previous light history.

From another point of view, individual lifestyle and daily routines may be related to socio-cultural background and behavioural factors that are not mostly accounted for in many studies, which may affect the perception of lighting quality. For instance, some individuals tend to spend more time outdoors culturally, and their lighting evaluation could vary from those spending mostly indoor due to high levels of light exposure.

Taken together, all these studies indicate that there is an impact of socio-cultural background and possibly related perceptional and behaviour patterns on daylight perception within the individual and contextual variability. For this reason, further research should be undertaken, and both socio-cultural and individual variations should be considered together.

4 Conclusion

This review aimed to create a conceptual framework of cultural background in lit environments to investigate an association between cultural background and daylight perception, expectation, and satisfaction. The review showed that factors thought to be influencing daylight perception in the cultural context have been explored in several ways. It firstly demonstrated that ethnicity and/or physiological properties of individual eyes affect daylight perception and preferences. Secondly, it provided evidence for the importance of the residential area's impact on the daylight perception of the people living in the same location and getting used to experiencing those conditions. Thirdly, it remarked the importance of the previous luminance environment and suggested that the prior light history should be considered under the combination of outdoor daylight availability and the subject's lifestyle and preferences for a sufficient time. Lastly, it stated that socio-cultural background and possibly related behaviour patterns impact daylight perception within the individual and contextual variability. Together these results provide valuable insights into daylight perception in the cultural context.

This review has confirmed the assumption that there are differences in how people perceive and feel about different lighting conditions due to their cultural background with various approaches. It also has remarked the lack of comprehensive knowledge of this issue regarding the perceived adequacy of illumination for people from different cultural backgrounds. A further study with more focus on daylight perception with the combination of the four cultural background approaches explained previously is therefore recommended. Also, more research on which approach is more influential on daylight perception needs to be undertaken before the association between cultural context and daylight perception is more clearly understood.

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Appendix 7.4: A proceedings paper entitled with "The impact of daylight availability on seat selection"

The title of the proceedings paper	The impact of daylight availability on seat selection
Authors	Gizem Izmir Tunahan, Hector Altamirano and Jemima Unwin Teji
Conference	2021 Illuminating Engineering Society (IES) Annual Conference at New York, United States
Date of publication	24/08/2021
Presentation	Oral presentation and publication
Access from	https://discovery.ucl.ac.uk/id/eprint/10137716/

THE IMPACT OF DAYLIGHT AVAILABILITY ON SEAT SELECTION

Izmir Tunahan G.[1,*], Altamirano H.[1], Unwin J.[1]

[1] Institute for Environmental Design and Engineering, University College London, London, United Kingdom

* gizem.izmir.tunahan.17@ucl.ac.uk

Abstract

Seating that meets students' needs and preferences could promote a longer stay in the libraries they use and keep students motivated, influencing their emotions and learning abilities. However, studies regarding seat preference in learning environments have mostly focused on interior elements, such as colours and furniture. Existing knowledge on the relationship between daylighting and seating preference is limited. This study aims to understand the contribution of daylight availability on seating preference.

In this study, participants were asked to select three best and three worst seat locations in a library and the most and least liked within those categories. Participants were also asked to indicate the reasons for their selection to examine whether the daylight in the selected desks (best and worst) coincides with those where daylight levels were high and low in order to understand whether the daylight component is an influential factor when deciding where to sit.

This study demonstrated that daylight is the most dominant reason when selecting desks, followed by privacy, outdoor view, and quietness. Although the reasons for seat selection varied, the majority of the participants agreed that satisfactory daylighting level, facing the least people, and a greenery outdoor view are particular reasons for seat selection. Future research is suggested where other reasons for seating selection are studied further; quietness, outdoor view, privacy, and their interaction with daylight.

Keywords: daylight; seat preference; library; students; seating behaviour.

1. Introduction

Academic libraries play a significant role in the learning development of students [1]. They should provide a good learning environment that enhances students' learning ability and contributes to academic and intellectual development [2]. Although the framework for planning and designing learning spaces such as academic libraries exist [3] [4], there is still a need for a better understanding of the specific needs of students to provide environments that meet their needs and preferences [5].

The concept of learning environment preference has been explained in environmental psychology using the physical dimensions (comfort, aesthetics, information and communication technology facilities, and layout), social dimensions (privacy, interaction, and autonomy), and sociodemographic dimensions (gender, age, study year, and life conditions) [6]. In other words, the preference for a learning environment is defined by the specific physical conditions of the environment and by human, cultural, and psychological dimensions. These factors greatly impact the students' emotions, learning ability, and feelings of belonging to a space [7], hence, the students' behaviours and seat preferences in libraries [8] [9].

The seat selection process has been asserted as a result of the individuals' prior experiences in that space or deliberate choices among alternatives while entering the space [10], regardless of whether deciding consciously or unconsciously [11]. This assumption has also been supported, indicating that seating decisions could be different for individuals familiar and unfamiliar with the physical settings in the space [12] because the human response to the physical environment is strongly subject to prior experiences [13]. In that case, users of a library could choose the same seat repeatedly as developing preferences depending on previous experiences, against first comers who need to rely on external sources of information. The degree of freedom of choice could also influence the seating decision because individuals can choose only available seats or space. For instance, in the early morning hours, individuals could have more chances to select a space than those who arrive in the afternoon. Individual differences, namely arousal, motivation, and expectation, also matter in human behaviour [13], influencing the decision-making process.

Seating features that meet the students' needs and preferences could aid a longer stay in the library [14], keeping students happier and more motivated [15] [16]. Understanding occupant behaviour and their interaction with the indoor environment could help improve the occupants' satisfaction [17] and the energy efficiency of buildings [18] [19]. However, occupant behaviour is a complex subject, as are the many external and internal aspects influencing behaviour (e.g., external environmental conditions, building characteristics, and indoor environment conditions; and biological, psychological, and social aspects [20] [21].

Studies regarding seat preference in the learning environment have mostly focused on interior elements, such as desk partition, colours, and furniture [14]. However, the existing knowledge of the association between daylighting and seating behaviour remains somewhat limited and needs further investigation [22]. This study aims to understand the relationship between daylight availability and seat preference and hence the spaces with higher demand in the context of the library. The research questions addressed in this paper are, therefore, as follows:

1. What are the underlying factors for choosing a seat in the library?
2. What is the importance of daylight on seat selection?

2. Methodology

2.1. Experiment

MSc students were asked to choose three best, and three worst seat locations from a library's seating plan and the most and least liked within those categories. They were also asked to indicate the reasons for their selection to examine whether the daylight in the selected desk (best and worst) coincides with those where daylight levels were high and low, respectively, hence if daylight component is an influential factor when deciding where to sit. The study took place on a sunny day in December 2019 between 13:00 and 14:00. In this study, the daylight availability of the selected desks was assumed to indicate the participant's daylight perception and expectation [23] [12].

2.2. Field site

The study was carried out in the UCL Bartlett library located in a six-storey building on the ground floor. The library comprises three main study areas (Figure 1). The *group study area* (Room 1) accommodates eight shared desks and four individual cubicles and has two side windows in the north-facing external wall; the *library collection area* (Room 2) has twelve shared desks and eleven individual desks and several side windows facing north and east orientations; the *quiet study room* (Room 3) is an open-plan space with a skylight, and thirty-two shared desks.

Figure 1: The plan of the Bartlett Library

2.3. Questionnaire design

A questionnaire was designed using a mix of multiple-choice, Likert scale, and open-ended questions. The questionnaire contains four sections; the first two sections of the questionnaire were completed by participants before entering the library and considered information regarding (1) demographic; gender, and age, and (2) time spent in London (months). The following sections considered specific tasks to explore the influential reasons on students' seat selection and the role of daylight conditions; therefore, section (3) focused on the selection of the three best and three worst seating places in the library and the reasons for the selection, and section (4) the subjective evaluation of daylight availability at the best seats selected.

2.4. Quantification of daylight availability

AutoCAD and Rhino were used to create parametric modelling, and an advanced level of Grasshopper was used to run lighting performance analysis with Ladybug and Honeybee plugins. Spot measurements were also used to validate the simulation results with real measurements.

2.5. Method of analysis

All the statistical analyses were conducted using the software package SPSS 20.0.

Analysis of seat preference of the participants: Initially, influential reasons for the best and worst seat selections and the importance of daylight in the selections were considered. Secondly, daylight availability at the best seat selected was evaluated using ordinal regression. Lastly, the best and worst seat selections were assessed on the seating map considering other influential factors apart from the contribution of daylight.

Analysis of daylight simulations: Daylight availability at each seat was calculated using point-in-time climate-based calculations, which has been found to have a better association with predicting daylight availability than other daylight metrics [24].

3. Results and Discussion

3.1. Seating preference in the Bartlett Library

Selection of best seats

The study findings show that daylight was the most dominant reason (36%) of all reasons given by participants when selecting the most liked desk, followed by privacy(18%), outdoor view(13%), and quietness(10%), respectively (Table 1). These results are in line with [23] and [12] findings that daylight was the most significant reason for seat selection. In this study, other specific features of the desk selected seem to be influential on seat selection (8%). Some of the specific features mentioned were wideness, proximity to the circulation route or entrance, enabling to study individually or with friends, being at the corner or the back of the room, and access to facilities such as a computer or plug socket. Participants also mentioned reasons related to indoor conditions (7%), such as temperature and air quality of the room. The proximity to windows was also mentioned (8%); however, it is unclear if it could be due to daylight or outdoor views.

Table 1: Participants' responses concerning the reasons for choosing the best seats in the library

Reason for best seat selected	*Total number of mentioned*	*A Best place*	*B Second-best*	*C Third-best*
Quietness	*10% (22)*	*10% (8)*	*9% (7)*	*10% (7)*
Daylight	***36% (81)***	*34% (28)*	*39% (29)*	*34% (24)*
Proximity to window	***8% (18)***	*9% (7)*	*5% (4)*	*10% (7)*
Outdoor view	*13% (30)*	*13% (11)*	*15% (11)*	*11% (8)*
Privacy	*18% (42)*	*21% (17)*	*21% (16)*	*13% (9)*
Desk features	*8% (18)*	*6% (5)*	*7% (5)*	*11% (8)*
Indoor conditions	*7% (16)*	*7% (6)*	*4% (3)*	*10% (7)*
Total responses	*227*	*82*	*75*	*70*

Selection of worst seats

Following the best seat selection, participants were also asked to state the three worst desks and the reasons for their selection. As seen in Table 2, the worst seats were also associated with unsatisfactory daylight conditions (33%), and with specific desk features (14%), nonprivate environment (12%), distractive noise (11%), and lack of or unpleasant outside views (6%). Although daylight remains the most dominant factor in seat selection, the order of importance in the worst seat selection is slightly different from those selected as best. Also, a group of people (11%) stated that some desks were the worst since they made them feel cramped or found some places claustrophobic (desks facing a wall). They also mentioned the lack of visual contact with other students or desks located in the corner of a room as reasons for their selection. These findings are interesting since most of those reasons were also considered positive features for some participants. For instance, the desk that made a student '*feel confined*' was suitable for another that considered it a place for '*easy to concentrate*'. Although seat preference varied from person to person depending on individual needs and expectations, most participants agreed that selecting a desk in the library is influenced by a satisfactory daylighting level, facing the least people, and a greenery outdoor view.

Table 2: Participants' responses concerning the reasons for choosing the worst seats in the library

Reason for worst seat selected	*Total number of mentioned*	*1 Worst place*	*2 Second-worst*	*3 Third-worst*
Noise	11% (21)	8% (6)	13% (8)	12% (7)
Lack of /insufficient daylight	**33% (62)**	34% (24)	32% (20)	32% (18)
No window	**4% (7)**	4% (3)	2% (1)	5% (3)
Lack of/ unpleasant outdoor view	6% (12)	6% (4)	6% (4)	7% (4)
Privacy	12% (23)	16% (11)	11% (7)	9% (5)
Desk features	14% (26)	13% (9)	16% (10)	12% (7)
Indoor conditions	9% (18)	8% (6)	9% (6)	10% (6)
Feeling cramped	11% (21)	10% (7)	11% (7)	12% (7)
Total responses	190	70	63	57

3.2. The role of daylight on seat selection

Figure 3 presents the seat preference configuration against the library's daylight availability when the experiment was conducted. It can be seen that most of the seats selected as the best are located in areas with high illumination, whereas most unpopular desks are located in places with poor or lack of daylight. The categorisation of lighting levels was done based on the recommended range for library reading rooms (between 300 and 500 lux) [12]. Interestingly, similar to previous findings, two desks were regarded as both best and worst by different participants. One of them, located in Room 1, corresponds to an individual cubicle that does not have access to outdoor view or acceptable daylight levels. The desk was selected as the worst seat by a participant because of the deficient daylight level; however, another participant preferred it because the desk was at the corner and provided a private environment. Another desk described as both best and worst by some participants is located near the window and in the corner of Room 2. The desk has a satisfactory daylight level and a greenery outdoor view, which some participants positively appraised. However, others were negatively affected, given its closeness to an emergency exit and people passing through circulation.

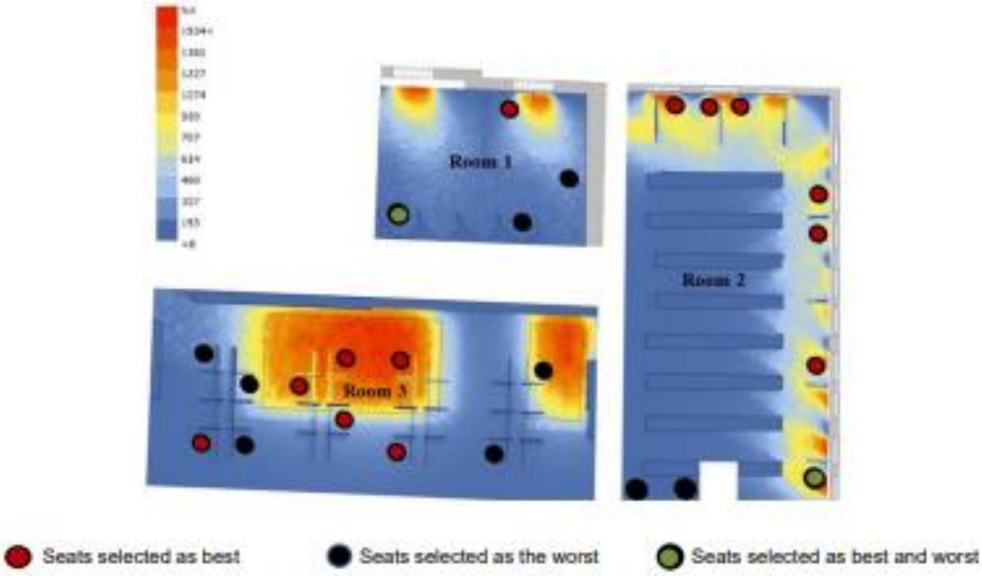

Figure 2: Best and worst seat selected by participants against daylight availability

Even though seat selection seems associated with daylight, its role may vary depending on the context, sample characteristics, and the activities participants are requested to undertake. For instance, this study's results could have been different if the participants were in real need of using the space for their specific academic tasks (e.g., reading and writing for an assignment). In that case, privacy and quietness would have been more important than natural environment components such as temperature, lighting, and outdoor view. Therefore, the study design might have affected the participants' natural environmental attention and evaluation of the space and desks. Nevertheless, although the importance of daylight varies from study to study, it always remains an essential factor for seat selection.

3.3. Assessment of daylight availability at the best seat selection

Following the best and worst seat selection, participants were required to describe the daylight conditions at their best seat desk. The daylight availability at the best desks selected by participants showed that 44% of the participants (N=22) described the amount of daylight on their best desk as very high, 42% (N=21) stated that the daylight conditions were high, and 6% (N=3) as above average. In contrast, only 8% characterised the conditions of the best-selected desks as low or very low. These results support the idea that most people prefer desks with a high amount of daylight, which could be with or without consciousness [11].

3.4. Combination of reasons for seat preference

Although daylight on its own seems to be a critical component for seat selection, its combination with other factors should also be considered. In this study, participants were required to state at least one and ideally three reasons for selecting a desk. Table 3 and 4 shows the combination of reasons for choosing the best and worst desks. As supported by previous findings, the combination of daylight and outdoor view and daylight and privacy are critical combined reasons for selecting seats. Also, people avoid selecting places with insufficient daylight and a cramped environment, followed by places with an unacceptable level of daylight and outdoor views.

Table 3: Frequency of mentioned reasons for the best seats selected

	Desk features	*Indoor conditions*	*Daylight*	*Outdoor views*	*Privacy*	*Quietness*
Desk features			2			
Indoor conditions						1
Daylight	1	1		7	4	2
Outdoor views					1	
Privacy	1	2	2	1		1
Proximity to window		1	1	1	1	
Quietness			1		1	

Table 4: Frequency of mentioned reasons for the worst seats selected

	Insufficient Daylight	*Desk features*	*Indoor conditions*	*No window*	*Noise*	*Unpleasant outdoor views*	*Privacy*
Insufficient daylight			1	1	2	4	
Desk features	2			1			1
Indoor conditions							1
Feeling cramped	6		1			1	
Unpleasant outdoor views	1						2
Privacy	2		1	1	1		

3.5. Seat preference in the different rooms

The Bartlett Library was selected due to the different configurations of rooms it provides. While two of the rooms (Room 1 and 2) have side windows allowing the students to access daylight and outdoor views, Room 3, an open plan space, is located under a skylight without outdoor views but sufficient daylight levels, especially at some desks. Therefore, is there any difference in the seating preference between rooms? If so, a difference in seat preference between spaces lit by the side windows and skylights?

Most students (54%) selected as best the desks located in Room 2, given the access to both daylight and outdoor views. However, the percentage of preferred desks in Room 2 in one of their three favourite seats is higher for individual desks than shared desks. Desks in Room 1 were also regarded as good by students (26%). Most of those students preferred to sit down near the window at the shared desks, while others preferred the individual cubicles with no daylight and outdoor view access. On the other hand, only 20% of students selected the desks in Room 3 as the best, mainly the desks given access to excellent daylight availability. There was a tendency of students in Room 3 to select the desks with higher illumination. For instance, the desks getting a high amount of daylight under the skylight were preferable (16%) than the desks with inadequate or lack of daylight (4%). The preferred desks with low daylight levels are located in the corners of the room.

The room lit by skylight was less preferable than the rooms lit by the side windows despite the high amount of daylight. It could be argued that access to outdoor views and acceptable daylight levels makes the seating places more preferable than only daylight. However, outdoor views and daylight are not separate things to participants because people do not value each environmental variable equally for seat selection [11]. Also, privacy could be another important component because the place lit by skylight is an open plan space and comparatively less private than other rooms. These findings emphasised that although daylight is the most dominant seat selection factor, seat preference cannot be explained by daylight alone. It should be investigated together with other components such as privacy, outdoor views, and quietness because the seating configurations of the rooms were very different from each other.

3.6. Limitations

The study was limited to a particular place and group of people at a given point in time. The activities participants were requested to undertake might have influenced the participants' seat selection. Since the order of importance in seat selection could have been different if the participants were in real need of using the space for their respective studies. In that case, privacy and quietness could have been more important than natural environment components such as temperature, lighting, and outdoor view, because a degree of privacy [25] and a quiet environment [26] are the most important components at especially exam periods helping students improve concentration.

4. Conclusion

Linking the seating behaviour of individuals with a particular stimulus in the physical environment is quite difficult because individuals are exposed to multiple sources of information during seat selection. The factors influencing seating behaviour in the learning environment have been defined in various studies as ambient temperature, type of furniture, proximity to other occupants [23], quietness, outdoor view, privacy, social interactions such as close to friends, entrance or circulation [27], daylight [24] [28], students' degree of territoriality and seat arrangements [29]. It is also known that when choosing a space, individuals tend to value a few specific variables rather than evaluate each environmental variable equally [12]. Underlying processes of seating behaviour within a specific physical environment have not been completely understood yet. The impact of daylight on seating selection is also affected by the variations in other factors that influence the decision-making process.

In this study, we have shown that daylight was the most dominant reason given for selecting the best desks in the library, followed by privacy, outdoor view, and quietness, respectively. Although the reasons for seat selection varied, the majority of the participants agreed on; satisfactory daylighting level, facing the least people, and a greenery outdoor view.

The study also revealed that daylight conditions significantly influence seating preferences in places daylit by side windows rather than a skylight. It could be explained that access to outdoor views and acceptable daylight levels makes certain areas more preferable. Another finding of the study was that the seats with a good combination of daylight and privacy are in more demand than the seats providing only an appropriate daylight level when all seats have access to similar outdoor views.

Although daylight has a vital role in seat selection, other factors, such as quietness, outdoor view, and privacy, need further consideration. Future research should be devoted to developing an analysis method to investigate seating selection with solely daylight and its interaction with other components.

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Appendix 7.5: Postdoctoral research project in the UCL libraries

Postdoctoral research project:

Developing strategies to increase students' place attachment to UCL libraries

Introduction

The learning environment constitutes one of the most critical aspects of students' cognitive and academic performance. Therefore, it is crucial to understand and consider the factors that influence students' needs and expectations in a library because being aware of their preferences makes it possible to design functional, comfortable and high-quality spaces.

Why needed?

- PhD research project showed that 65% of students spending time at the Bartlett Library think that the indoor environment of the library should be improved, especially at specific places that they commonly pointed out as uncomfortable. It is quite important because satisfaction with the learning environment brings more motivation and easier concentration.
- Study findings showed that daylight was the most dominant reason for selecting the most liked desk at the library; however, there are many components that need to be considered while investigating the students' seat preferences, such as temperature, outdoor view, privacy, noise, etc.
- The research project showed that cultural background seems important for students' daylight perception and expectation, and ultimately their seat selection. However, it needs further investigation with a large number of students not limiting with light conditions only, with also other environmental components. Investigation into the impact of cultural background on the environmental perception of students could be only possible in a multicultural environment like UCL.
- UCL has 18 libraries and special collections. While Student Centre(52.2%), Bartlett Library(48.4%), and Main Library(37.3%) are some of the most demanded libraries by students, surprisingly, a few libraries are not occupied as much as others. Therefore, the reason why some libraries are more attractive than others needs further investigation to reduce unnecessary energy consumption in less demanded libraries as well as increase students' satisfaction and learning performance.

Research questions

- Which environmental factors are more important for students' seat selections?
- What kind of places /indoor features/ libraries are more and less in demand at the UCL libraries? How can we improve less demanded libraries/ places?
- What is the role of cultural background on environmental perception and ultimately students' seat selections?
- What is the contribution of interventions to students' seat selection, satisfaction and learning performance?

Aim and objectives

The project's main aim is to increase students' feeling of belonging to libraries and improve their satisfaction and learning performance considering various indoor and personal components. Objectives are:

- to identify the less demanded places and reasons with students' statements and occupancy data
- to develop strategies based on students' needs and preferences and make interventions
- to analyse the change in seating behaviour of the students before and after interventions with students' statements and occupancy data
- to increase the number of students visiting to the libraries with less demand
- to reach the highest number of students from different cultural backgrounds
- to present the research findings in many conferences and publish research papers as much as possible

Methodology (all necessary equipment will be provided from IEDE)

This research project involves five main stages and benefits from surveys, interventions, environmental loggers and occupancy data of the selected libraries.

First stage is the analysis of the libraries considering the fixed features of the spaces and classification of the seat places. These features are the type of furniture, divider panels, seating arrangements, proximity to other seats, the privacy of the student and laptop screen, outdoor view from the sitting point and indoor atmosphere.

Second stage is conducting a survey at specific libraries with the maximum number of students. Prior to surveying, some environmental loggers will have been installed into the specific points of the libraries to measure indoor temperature, noise level, daylight level and air quality when students fill the survey. To compare the student's responses with environmental components, each student will be required to note surveying time on the first page of the questionnaire.
In the survey, students will be asked their reasons for selecting that seat, satisfaction level with the indoor conditions and seating space and how that space contributes to learning performance. Some personal questions such as age, gender and cultural background will be asked as well.

Third stage involves the identification of the less pleasant places at the libraries from the previous stage and making some interventions at those places. These inventions could be even minor changes to get more attention to those places. For example, if a place is not selected because of lack of access to daylight, the LED sun that is an artificial light completely mimicking properties of natural sunlight could be used to increase the belonging in the space. Also, some seat places facing walls are found very claustrophobic by some students. In this case, an internal green wall could be built on the part of the wall to overcome the poor conditions that students describe. The interventions will be discussed later with the budget.

Fourth stage is the repetition of the second stage with the same procedure. It only differs with additional questions about the intervention elements. It aims to investigate the changes in seating behaviour of the students before and after interventions and analyse if the intervention helps increase students' satisfaction with the space.

In the last stage, we will examine how the interventions affected students' seat selection, satisfaction with the space and learning performance. We hope to increase the number of students visiting less demanded places, improve their satisfaction with the indoor environment, and see considerable development in their learning performance.

Each step will be reported, published in scientific journals, and presented in prestigious conferences during all stages.

Contribution of the research project

We know that we cannot build the existing libraries again, but maybe we can re-arrange the seating planning, make changes in the interior design and improve the indoor environmental quality based on students' needs and preferences, thanks to our research findings. In this way, we can achieve to make students more satisfied and motivated and thus we can increase the number of students visiting the libraries.

We believe that a university welcoming students from all over the world like UCL will value how students perceive the indoor environment differently from each other and how we can improve the facilities to enhance their satisfaction and motivation. In this way, this research project could help increase UCL's reputation with research and publications and also rise up the university rankings by increasing the students' satisfaction and learning performance. Also, study findings could help to design more functional and comfortable library buildings in the future.