DIPLOMARBEIT

A Visual Performance Assessment of the National Library of Kosovo

unter der Leitung von

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KURZFASSUNG

Traditionell ist die Nutzung von natürlichem Licht - oder Tageslicht - ein wünschenswertes Merkmal von Gebäuden und ein Symbol für gutes Design. Seit Jahrzehnten werden Bibliotheksräume durch Volumen und Oberflächen definiert, die mit natürlichem Licht beleuchtet werden und ein blendfreies Lesen ermöglichen. Die Beziehung zwischen dem Leser, dem Licht und dem Buch ist von entscheidender Bedeutung, und die Qualität der Beleuchtung hat einen großen Einfluss auf die visuelle Gesundheit und die Lerneffizienz der Nutzer. Die Nationalbibliothek des Kosovo zeichnet sich durch Merkmale aus, die kontinuierlich zum wichtigsten Element der Funktionalität eines Gebäudeentwurfs beitragen sollen - der Verteilung des natürlichen Lichts. Die reichlich vorhandenen Acrylkuppeln, die als Oberlichter fungieren, und die vertikalen Öffnungen sollen für eine natürliche Tageslichtbeleuchtung sorgen. Andererseits helfen die Sonnenschutzstrukturen an der Glasfassade - auch als Brise-Soleil-Systeme bekannt - bei der Ablenkung des Sonnenlichts und der Verringerung der Wärmegewinne in das Gebäude. Im Laufe der Jahre haben diese Konstruktionsmerkmale dazu geführt, dass das Gebäude in Bezug auf seine optische Leistung umstritten ist. Im Laufe der Zeit haben einige Bewohner gezögert, die Lesesäle in den Abendstunden zu nutzen, da sie die Räume als dunkel beschrieben, während tagsüber eine erträgliche Blendung festgestellt wurde. Alles in allem kann das, was ursprünglich wie ein praktisches Bibliotheksdesign aussieht, im Hinblick auf seine visuelle Effizienz auch Nachteile haben. In dieser Studie wurde untersucht, ob die Integration der in der Bibliothek ausgestellten Beleuchtungsmethoden ein angemessenes visuelles Erlebnis, eine angemessene Wahrnehmung und einen angemessenen Komfort für die Nutzer schafft und gleichzeitig die Beleuchtungsnormen erfüllt. Die Studie konzentrierte sich auf neun Fallstudienräume des Gebäudes, die alle unterschiedliche Nutzungszwecke haben. Der Arbeitsablauf dieser Arbeit umfasst die Analyse der aktuellen Beleuchtungsstärke am Tag, die durch Messungen vor Ort erfasst wurde, während die Beleuchtungsstärke am Abend mit Hilfe von Simulationswerkzeugen für die Beleuchtungsleistung verfolgt wurde. Die aufgezeichneten Daten wurden anschließend mit den relevanten Kriterien der Beleuchtungsnorm verglichen und es werden Verbesserungsvorschläge gemacht, indem die von den Beleuchtungssimulationswerkzeugen unterstützten Prozesse zur Lichtplanung genutzt werden. Abschließend wurde eine Fragebogenerhebung zum Zweck der allgemeinen Bewertung des Komforts der Bewohner durchgeführt. Die Analyse überprüfte die Hypothese, dass die Bibliothek im Allgemeinen die normativen

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Beleuchtungsstärkeanforderungen nicht erfüllt und ihre visuelle Leistung daher als unbefriedigend eingestuft wird. Die gesammelten Daten ergaben, dass das Gebäude einer umfassenden Renovierung bedarf, um die visuelle Erfahrung, die Wahrnehmung und den Komfort der Nutzer zu verbessern, insbesondere im Hinblick auf das künstliche Beleuchtungssystem.

Keywords

Visual performance, Visual comfort, Illuminance, Daylight Analysis, Artificial Lighting Analysis, Improvement Proposal, Lighting Norms, Questionnaire.

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ABSTRACT

Traditionally, the use of natural light – or daylighting, has been a desirable building feature and a symbol of good design. For decades, memorable library spaces have been defined by volumes and surfaces illuminated with natural light, allowing a glare-free reading. The relationship between the reader, the light, and the book, is very crucial, and the quality of lighting has a great influence on the visual health and learning efficiency of the occupant. The National Library of Kosovo has distinguishing features that are intended to continuously contribute to the most vital element of functionality of a building design - the distribution of natural light. The abundant availability of the acrylic domes acting as skylights and the vertical openings are considered to supply natural daylight illumination. On the other hand, the sunshade structures on the glass façade–also known as brise-soleil systems–help with deflecting sunlight and reducing heat gains into the building. Along the years, these design features have made the building a subject of discussion in terms of its visual performance. Throughout time, some occupants have shown hesitation on using the reading rooms during the evening hours, describing the rooms as dark, whereas during the day mild glare is reported. All in all, what originally looks like a practical design of a library can have its setbacks with regards to its visual efficiency. This study tested and examined further if the integration of the illumination methods exhibited into the library are creating an adequate visual experience, perception, and comfort for its occupants, while at the same time meeting the lighting norms. The study focused on nine case study rooms of the building, all with different usage purposes. The workflow of this thesis involves analysis of the present daytime illuminance recorded via in-situ measurements, whereas the evening illuminance is followed by lighting performance simulation tools. The recorded data was thereafter compared with the relevant lighting standard criteria and thus, an improvement proposal is suggested. By the end, a questionnaire survey for the purpose of the general evaluation of occupant's comfort was carried out. The analysis tested the hypothesis that in general, the library does not meet the normative illuminance requirements and therefore its visual performance is deemed as unsatisfactory. The collected data revealed that in order to improve the occupants visual experience, perception and comfort, the building needs important renovation, particularly for its artificial lighting system.

Keywords

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Faleminderit shumë!

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1 INTRODUCTION

1.1 Overview

Since the beginning of times, sunlight has warmed human habitat and thus has remained a primary factor when designing habitations. The use of natural light, or *daylight,* has traditionally been a desirable building feature and a hallmark of good design, and incorporating sunlight was a fundamental design element in buildings of many civilizations (Boubekri 2014). The overall success of a library lies behind a lot of elements, an important one being good lighting. Tregenza (1998, p.63) states that *"Underlying all design criteria there is one single idea: the purpose of lighting is to give information".* It has been estimated that 90% of the information we obtain from our senses is received via sight. The relationship between the reader, the light, and the book, is very crucial. Thus, the changing behavior of daylight is essential for our visual, psychological, and biological needs. Different analysis of libraries throughout the years have demonstrated just how complex the notion of a "good reading light" is, and it is by now evident that natural light is vital as an illumination source in library design. The effective use of natural lighting can not only reduce the visual fatigue of the readers, but also benefit the physical and mental health, improve the efficiency of work and study, and reduce energy consumption to a certain extent. The case study library building has distinguishing features that are intended to continuously contribute to the distribution of natural lighting. Yet, it is unclear if the abundance of natural light – or the lack thereof, is providing the occupants with adequate visual comfort or not. Within the framework of this thesis, lighting performance of nine spaces of the National Library of Kosovo (referred to as NLK in the future) will be evaluated. It is therefore of interest to analyze how illumination means of the building are being successfully integrated to the overall functionality of the library. Moreover, further exploration on how the lighting dilemmas (if any) are affixed to the occupant's experience, perception, and comfort will be elaborated. In the first chapter, objectives, motivation, and fundamental background will be given. The second chapter includes the introduction of all the spaces, the used measurement equipment, the applied lighting software tool and the relevant recommendations will be presented. Additionally, a questionnaire is conducted to observe the occupant's visual comfort and all the obtained results is presented consequently and discussed to conclude the general findings, challenges, shortcomings, and future research opportunities.

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1.2 Motivation

For human beings and other life forms, light is the most important medium for transmitting visual information about the environment. Reading on the other hand, is the most fundamental task in a library. The aim of library lighting strategy is to provide good reading light to create an intimate space for the reader, most importantly while catering to the visual comfort perception (Boubekri 2014).

Citing Louis Kahn: *"As soon as I see a plan which tries to sell me spaces without light, I simply reject it with such an ease, as though it were not even thoughtfully rejected, because I know it is wrong. And so, false prophets, like schools that have no natural light, are un-architectural. Those are what I like to call – belong to the marketplace of architecture but not to architecture itself"* (Latour 1991).

The NLK is a distinctive building which has always enticed interest to the critic's eye. It is rather regarded as a controversial building where many architecture critics find the library as the epitome of ugly, while others, on the other hand, are captivated by the level of detail put into its design. The main purpose of conducting this thesis is to determine whether the design decisions made by design professionals are providing the performance that the user demands. As the lighting being the most prevalent feature to contribute to the physical and psychic demands of the occupant, it is therefore of upmost importance to identify first the influencing factors that will be analyzed as part of the process. This colossal building is covered with translucent domes providing zenithal illumination and a grid covering wrapped around the façade in a so called brise-soleil system (sun-breaker), contributing to the sunlight deflection for the interior. It is imperative therefore to address these concerns in a systematic manner; by providing an analysis on the integration of the daylight – or the lack thereof, inside the case study rooms and prove how this is contributing to the overall success of the library.

Figure 1 - Aerial view of the library (Kosovo Architecture Foundation 2018)

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1.3 Background

1.3.1 Overview

Considering that the NLK is in use from 1982, there have been some observations and assessments throughout time, however most of them focused their attention on the overall building structure and its ability to perform as a functional space. More specifically, the structural concerns such as the façade corrosion, conservation and renovation possibilities, and water infiltration from cellars and domes were points of interest. All these factors, of course, are very important features that affect mostly the comfort of the occupant; however, they are not pertinent to this study.

Moving forward, a group of conservation specialists (Kosovo Architecture Foundation 2015) investigated the building, where among other interests, they identified illumination as a main concern. According to their study, the light levels are adequate in some study rooms during the day however at night they are far below the standards. Moreover, the library is said to still use old lighting fixture systems contributing to overall higher energy costs. Although results of the study provide valuable information – which will be used as a consideration for this work too, up to now there is no other evidence of a comprehensive analysis for the integration of daylighting. More importantly, an inclusive study of illumination levels in the important spaces of the library, particularly the chosen spaces for the study, has not been done yet.

Post occupancy evaluations are meant to evaluate buildings in a *"systematic and rigorous manner after they have been built and occupied for some time"* (Preiser, et al. 1988), however this is not the case here. Up to now, there is no manifestation of a substantial and holistic reading of the occupants' visual comfort which shows how effective the natural light is, affecting among others, the occupant's visual health and learning efficiency. The following chapters of the thesis will entail fundamental theoretical background about the topic in general. Firstly, as a keystone, several components of lighting design will be discussed. Criteria and concepts that play an important role on lighting design will be presented. Additionally, the reference lighting standard will be introduced, which are essential for this thesis and all other similar works that are related with lighting design. Moreover, thorough historical background information for the library will be provided, so that the reader has a deep understanding of the building design features that play an integral role for examination of this study.

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1.3.2 Photometric quantities of light

Luminous flux, intensity, illuminance, and luminance are all photometrics measurable quantities that we use to describe the amount of light in different situations.

- **Luminous Flux [Φ]**

Luminous flux (or flow of light) is a quantity derived from the radiant power, expressing therefore the total amount of light emitted through a light source. It also evaluates the radiant flux according to the sensitivity of the human eye. The unit of flux is the lumen [lm]. Flux is frequently used to compare lamp outputs and to get a sense of the total quantity of light required without regard to the direction of light flow or the surface to be illuminated.

- **Luminous Intensity [I]**

The luminous intensity is a quantity for characterizing a light source. It is rather defined as the luminous flux per unit solid angle of a light source. The term is most commonly used in the approximation of a point source, that is, at distances that are large in comparison to the source's extent. The unit of intensity is the candela which is equal to one lumen per steradian. Luminous intensity is almost always determined in an indirect manner: a value of intensity is inferred using the inverse square cosine law, an illuminance measurement, and the distance at which the illuminance measurement is made (DiLaura et al. 2011).

- **Illuminance [E]**

Illuminance is the measure of incident luminous flux per unit surface area. It can be expressed in lx (lx, lm/m^2) as well as in foot-candle (fc, lm/ft^2). Since the orientation of a surface is definable (e.g., vertical, horizontal), the orientation of illuminance can also be defined in the same way, for example, vertical illuminance, horizontal illuminance, etc. Illuminance does not indicate the direction of incident luminous fluxes; instead, it refers to the overall amount of incident light. As a result, certain circumstances with extremely distinct luminous intensity distributions may have the same illuminance, which could mislead the lighting designer if no more information is available (DiLaura et al. 2011).

- **Luminance [L]**

Luminance is a measure of brightness of a surface, when looked at from a given direction.

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Its unit is cd/m^2. DiLaura et al. (2011, p.5.14) states, that *"luminance is perhaps the most important quantity in lighting design and illuminating engineering, as it is one of the direct stimuli to vision and many measures of performance and perception have been shown to depend on luminance".*

- **Uniformity [Uo]**

According to Zumtobel (2018), *"Uniformity U_O is the ratio between the lowest illuminance (E_{min}) and the mean illuminance level (E_{avg}) in the area to be evaluated. The result is a minimum level".* Because the human eye requires time to adjust to new lighting conditions, rapid illuminance reductions or frequent illuminance shifts within the visual field can result in tiredness, tension, and discomfort. Therefore, there should be no significant changes in brightness when doing visual tasks in illuminated environments. In other words, uniformity can be simply calculated as:

$$Uo = Emin/Eavg$$

(Eq. 1)

- **Glare**

A saturation effect or an extreme contrast might generate glare. Depending on the extent of the effect, we can distinguish between discomfort glare and disability glare. The glare of all luminaires that are in the room regularly can be evaluated with the UGR method, as specified in the standard EN 12464-1 "Lighting of indoor workplaces" which suggests that the bigger the resulting UGR value, the greater the possibility of glare. The discomfort glare plays a significant role in the visual performance, which can either come from a direct source, or a reflected one (however this one, is rather caused by the reflective surfaces within sight). According to Zumtobel (2018), the magnitude of the glare depends on factors such as the location, luminance, size and amount of the light source, and the state of the eye adaption.

- **Luminous efficacy**

In the case of lamps, the luminous efficacy is a measure of energy efficiency, expressed in lumen per watt. Apart from the lamp itself, energy is consumed by the electrical equipment, particularly the ballast for gas-discharge lamps and the driver for solid-state lamps. For example, an incandescent lamp has a low efficacy because most of its power is radiated as heat, in the infrared part of the spectrum, not as light.

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- **Daylight factor**

The daylight factor predicts the available daylight in interiors. It is defined as the ratio of illuminance on a horizontal plane in an interior space due to light received from a defined luminance distribution sky (excluding direct sunlight) to illuminance on a horizontal plane in the open outside (without obstructions). Usually, the CIE intermediate sky and the horizontal plane are used as the standard situation. There are several sky distributions listed in the ISO/CIE Joint Standard, Spatial distribution of daylight – CIE standard general sky (ISO 15469 2004), however, many of the distributions are a function of sun position, thus, the daylight factor may be a function of time and date. The daylight factor is expressed in percentages (Van Bommel 2019).

- **Reflectance of surfaces**

The term reflectance specifies the ratio of the reflected luminous flux to the total luminous flux that are incident to a specific surface (Laughton and Warne 2003). Reflectance values of major surfaces and all the furniture in a room are the parameters which are generally out of lighting designer's control, however, they can make a significant contribution to increase the illuminance in an indoor space. Reflectance can be determined according to the Eq.2 below (Rea 2000).

$$\rho = \frac{L\pi}{E} \qquad \text{(Eq. 2)}$$

Where:

ρ is the reflectance value,
L is the luminance of a given point in cd/m^2,
E is the horizontal illuminance of a given point in lx.

1.3.3 Lighting standards

People can do visual tasks efficiently and accurately with adequate and sufficient lighting, including tasks performed over a prolonged time or of a repetitive nature. The degree of visibility and comfort required in a wide range of workplaces is regulated by the type and duration of the activity. It is therefore important that the lighting solutions for indoor spaces and their associated areas, to be specified and followed as per the lighting requirements. Since illumination can be provided by daylight, artificial lighting and/or the combination of both, the provided standards do not tend to limit the designers' freedom nor their use of innovative equipment.

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The European Standards for lighting are approved by the technical committee of European Committee for Standardization, also referred to as CEN. Given the history of Kosovo being partially recognized as a state due to war disputes, Kosovo is not yet a recognized member of CEN. However, CEN acknowledges Kosovo as a country who submits deliverables and the relevant design professionals still do use the international standards as benchmarks (CEN 2019).

EN 12464-1 – Lighting of indoor workplaces

According to EN 12464-1, the lighting requirements of each task area are defined in the following four main criteria.

- The minimum required maintained illuminance ($\bar{E}_m$), which represents the average illuminance
- The maximum limit of Unified Glare Rating (UGR)
- The minimum required uniformity (U_o)
- The minimum required Color Rendering Index (R_a)

EN 17037 - Daylight in buildings

This standard is planned to urge designers to evaluate and ensure successfully daylit spaces. It also allows building designers and developers to target goals with respect to daylighting, as well as addressing other issues related to daylight design, such as protection against glare, and exposure to sunlight.

Daylight can significantly impact the lighting needs of any type of building. This means that the openings should have appropriate areas to provide sufficient daylight throughout the year.

Thus, the evaluation of daylight should make account of the availability of daylight at the site in addition to accounting for the properties of the space, for example the opening properties i.e., if they are vertical, horizontal, or inclined (EN 17037 2019).

Among the above standards, additional recommendations were considered during the analysis such as:

- EN 12665: Light and lighting, basic terms, and criteria for lighting requirements.
- ISO 15469: Spatial distribution of daylight – CIE standard general sky.

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2 METHOD

2.1 Overview

To address the illumination of the NLK Building, nine crucial spaces of the library were selected and in-situ measurements through lighting measurement devices were performed. The in-situ measurements were performed during COVID-19 period, and therefore the opening hours of the library were limited for access. In normal circumstances, the library is open until 20:00PM however during January 2021 the country was experiencing major setbacks from the pandemic with curfew limitations in place, and the library was only open until 16:00PM. Considering that the study consists of the effect of daylight and the artificial lighting as well, the rest of the data were created by simulations, in order to obtain results for the evening hours at 19:00PM – where the daylight is not influential however the artificial lighting is. Following the in-situ measurements, the layouts of the spaces were modelled following the plans obtained by official representatives of the NLK, and consequently simulated via DIALux Evo. Considering that the visual comfort plays a major role in the overall performance of a building, and it is therefore crucial for this study in particular, a questionnaire was conducted and distributed to the users of the library. The multiple results from the in-situ measurement are exported and organized in Excel first for each individual recorded point (see Appendix A, namely Measuring Grids) and then averaged to give single values for each. In this work, the position of the measurement points will be highlighted on each case study layout plan. The averaged values retrieved from the in-situ measurements as well as the results from the simulations for evening hours will be presented accordingly. Moving along, the relevant lighting standard (see Table 1), which have been considered during measurements and taken as basis for the lighting performance evaluations, are introduced and referenced to the measured results. The visual comfort results are reflected via the results of the questionnaire. The following chapters will firstly include historical background information of the NLK, so that the reader has a broad understanding of the design choices made at the time, which are consequently coupled to the overall visual performance of the library in today's day and age.

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Thereafter, the selected space of the library – hereon referred as case study rooms – will be presented. Information of the measurement devices will be given and consequently the lighting evaluation criteria used as a basis will be presented. Finally, some information regarding the used software to simulate, and the content of the questionnaire will be introduced and explained.

2.2 Analysis parameters

When Croatian architect Andrija Mutnjakovic constructed the building in 1971, he sought to create an original national architectural statement that reflected the region's unique heritage and distinct cultural identity. The library is reminiscent of buildings from Byzantium and the Ottoman Empire, with in-situ cast concrete, marble floors, white plastered walls, and 99 translucent acrylic domes. Although the design received mixed reviews when it first opened in 1982, the building is now regarded as an exceptional example of late Yugoslav modernism and a beloved community space. The NLK has seen significant changes since its establishment in 1962. The library, which is regarded by the local community as the pinnacle of Albanian educational and cultural liberation in Ex-Yugoslavia, is and will continue to be the most important educational institution for the region's Albanian-speaking population for a long time. The dome structure is utilized to provide the greatest possible illumination for the library. The modern facade is similarly based on the cupola design, but with regionally suitable motifs. The physical and psychological demands of the reader influence the design and functional treatment of the primary interior space - the reading room (Kosovo Architecture Foundation 2018).

The reader's attention needs calm and confined settings. The building's exterior was designed to help with indoor illumination while also providing some shade and protection from the harsh summer heat. Shade was also necessary to create a more personal reading environment, which was done using the sun-breaker hexagonal system mounted on the exterior. The hexagonal motif has also been utilized on other significant structures around the world, such as the Lenin Museum in Tashkent.

The first and second floors, respectively, house the little reading room (for 100 readers) and the large reading room (for 200 readers). Special reading rooms for history, rare books, geography, graphics, music, films, and microfilm recordings are located on the second floor. Carrels for research workers are located on the third and fourth floors - the quietest parts of the library – and the Braille reading room is located on the main floor, with direct access from the street.

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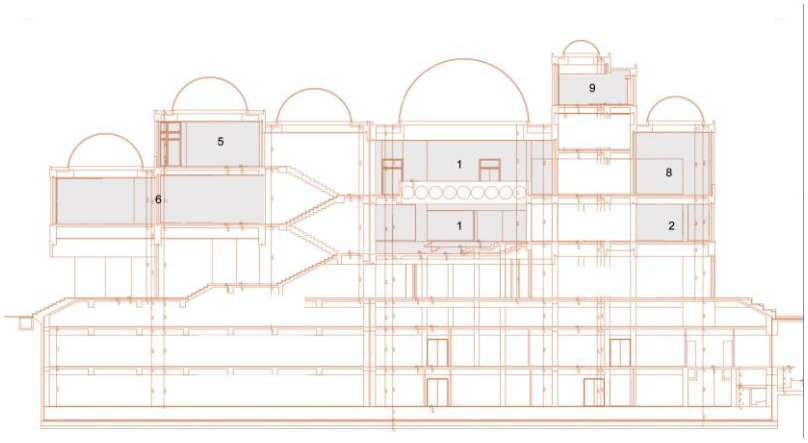

Figure 2 – Section view of the library with highlighted areas of measurement work (Adapted from source: Kosovo Architecture Foundation 2018)

The initial concept would be that public spaces, such as reading rooms, are located so that they allow zenithal light to pass through, and that spaces beneath them be used as auxiliary spaces, such as storage or similar. The domes of the NLK are one of the library's most distinctive features. The library has 99 domes, which are made up of triangular translucent plastic panels encased in metal frames, making it a prominent feature in Prishtina. When approaching the structure, the numerous "white bubbles" on the façade attract notice and pique interest. To create a unique atmosphere, the interior rooms are infused with soft, diffused natural light. In the reading rooms ample light is provided for study while in the central atrium sunlight is reflected off the decorative stone floor. The varied-sized domes are situated on various floors of the building, allowing natural light to flow throughout. The construction of the dome is made up of extruded aluminum panels that are bolted and welded together. This structure is sturdy, light, and well-detailed, and it keeps white translucent plastic panels in place.

2.2.1 Furniture, surfaces and materials

Before proceeding with elaborating each case study room, it is safe to mention some information regarding the furniture, materials and surfaces used on each room – as they are important for evaluating the reflectance of major surfaces. In general, all the furniture in the library were designed and produced solely for this library, in order to pair with the overall concept of the library design.

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The most important furniture to mention for this study are the ones concerning the reading rooms – which consequently are used for other rooms such as the conference rooms and auditoriums. The chairs and table desks of the reading rooms have a wooden structure whereas the top of the chair and the desks is layered with leather, so that it gives a softer and warmer feeling to the user. The desks have a higher upper partition, layered with black glass for absorbing the incident light. Figure 3 represents the common room furniture. All other chairs and desks of the library are from wood, such as the conference room, two auditoriums and the exhibition hall (which also includes glass coverings for the exhibition cabinets).

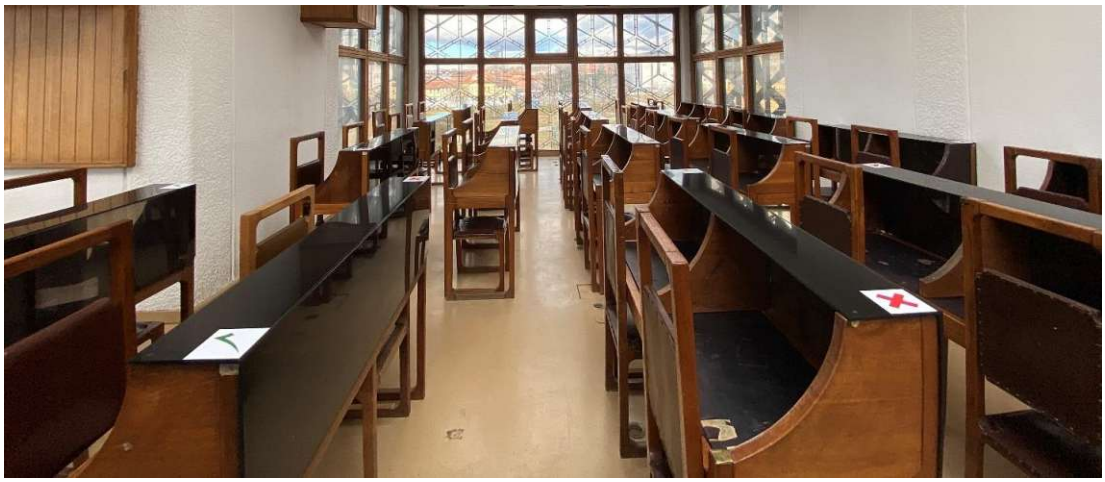

Figure 3 – Reading room furniture, wall surfaces and other materials

2.2.2 Artificial Lighting System

According to examinations made during the in-situ visits, it is recorded that the library has a manual system for switching the lights on/off, depending on if the space is in use or not. According to KAF's study, it was noted that the library is still using old mercury-vapor lamps as bulbs for the ceiling mounted luminaires.

Figure 4 – Artificial Lighting System (Kosovo Architecture Foundation 2018)

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2.3 Case Study Rooms

The nine evaluated rooms of the NLK are:

1. Entrance/Reception
2. Administration Office
3. Conference Room
4. Auditorium
5. Book Club Room
6. Exhibition Hall
7. Main Reading Room
8. Secondary Reading Room
9. Private Reading Rooms

2.3.1 Case 1 – Entrance Hall – Reception and Lounge Area

The main entrance hall is located on the ground floor together with most of the administration offices. The room has a central orientation, where the daylight provision comes from the main dome – the biggest of the building. The evaluation in this room has been done for the reception area and the lounge area.

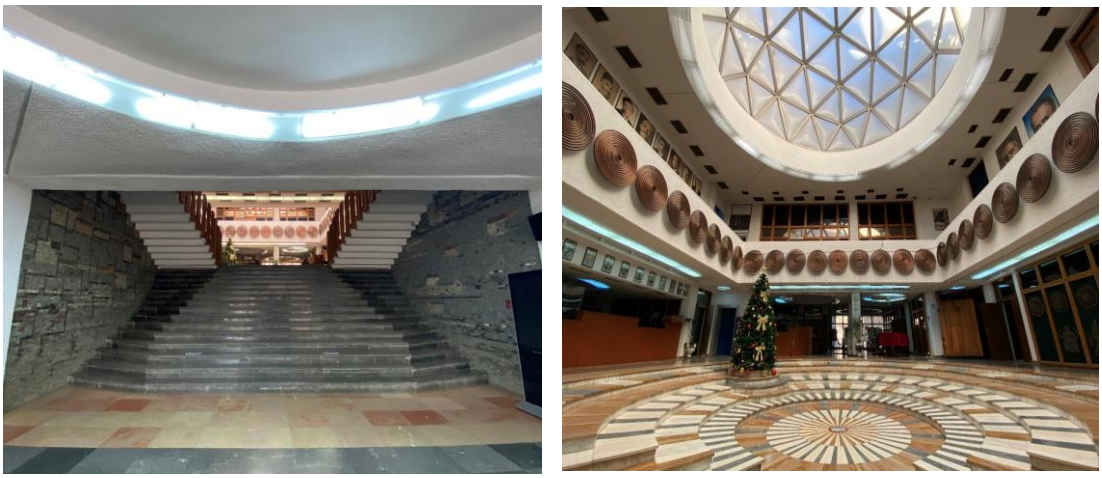

Figure 5 – Entrance Hall

2.3.2 Case 2 - Administration Office

Although the library has several offices, one office was used as a case study. As seen from the photo, each dome has artificial lighting bulbs underneath, however they are mostly not turned on during the day, as this was also recorded as the occupant's preference. As such, during the evaluation time, the artificial light was switched off and evaluated only with the availability of daylight from the dome.

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Figure 6 – Administration Office Type 1 and 2

(Adapted from source: Kosovo Architecture Foundation 2018)

2.3.3 Case 3 - Conference Room

The conference room, or also called as the round-table room, is a small room that is only accessed internally from the staff. It is located west of the building, with vertical openings on the west façade, and has an available dome.

Figure 7 - Conference Room

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2.3.4 Case 4 - Auditorium

The library has 2 types of auditoriums and both of them were chosen to be evaluated for this study. The big auditorium is used also externally for guests that can rent the room for events. It is located on the second floor but has a sub-level on top for audience that prefers to stand. In most cases, the sub-level is used for news outlets (cameras, production etc.). The dome provides zenithal illumination, and it is recorded that in most cases when there is an event, the artificial lighting is always turned on. For this examination, the lamps are turned off, to check the daylight illumination results.

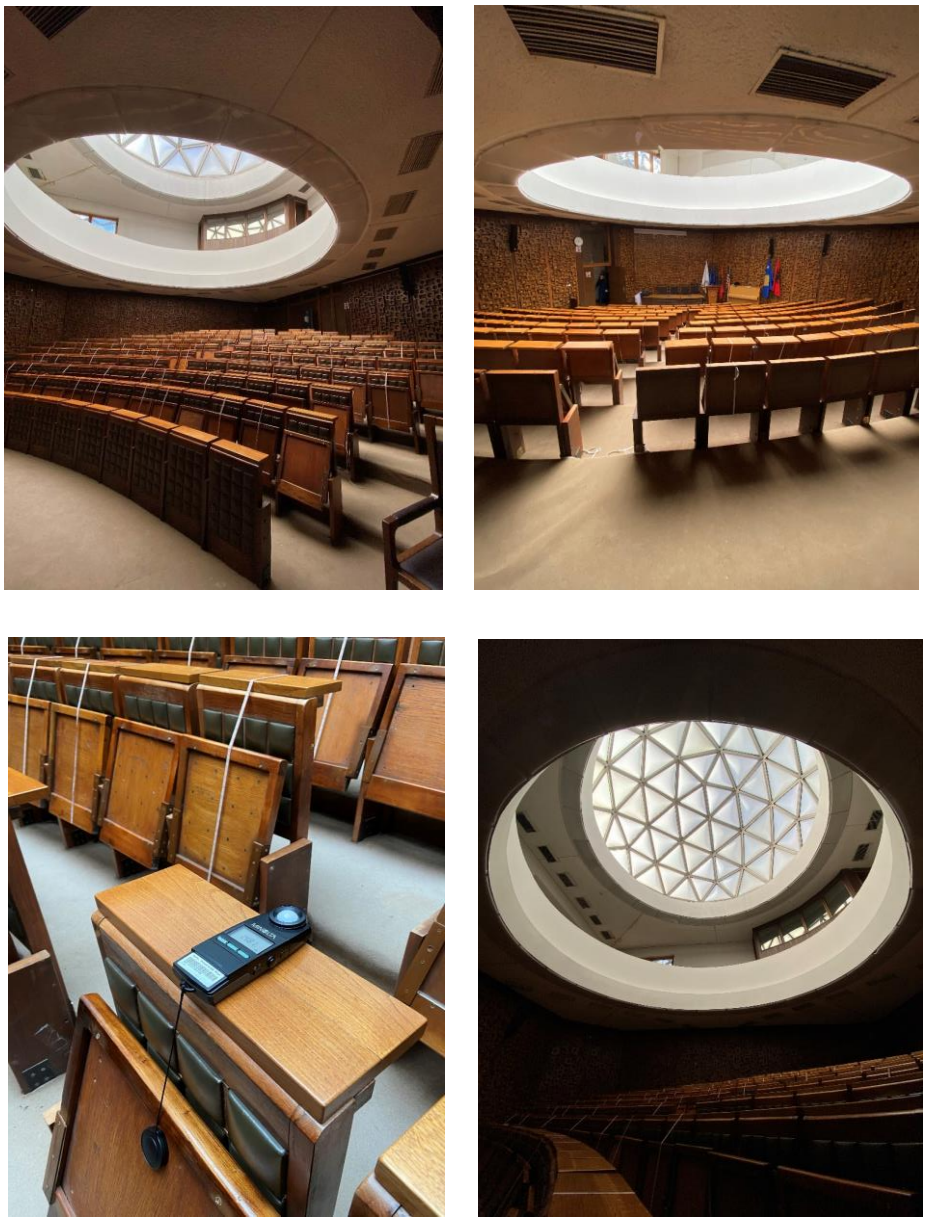

Figure 8– Auditorium

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2.3.5 Case 5 – Book Club Room

The small auditorium on the other hand, is considered more as a gathering room where guests can discuss books and also organize book launch small events. The room can gather up to 40 people. During the evaluation, it was kept under consideration that since the main area of activity of this room is while sitting, and no desks are available, the work plane level would be less than 0.80m.

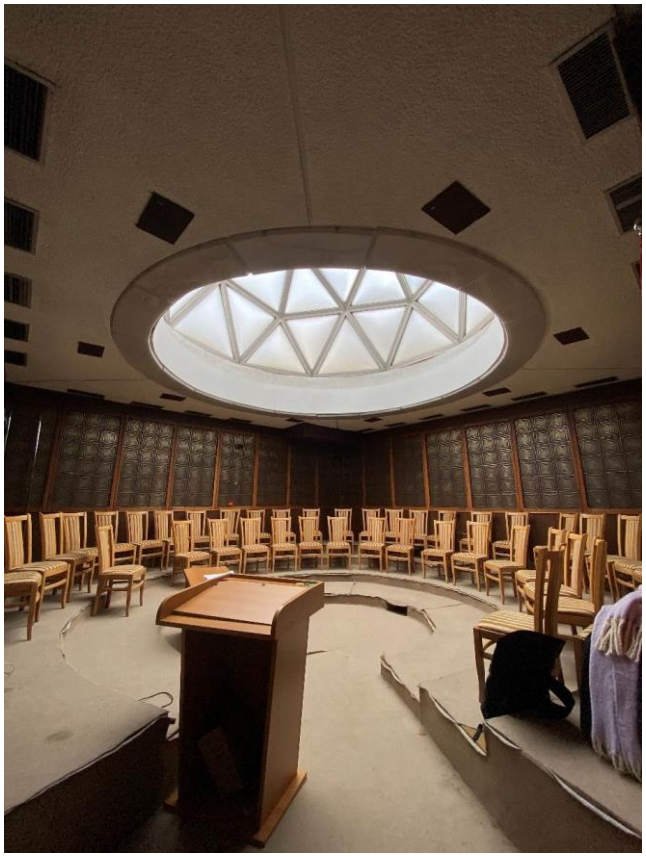

Figure 9 – Book Club Room

2.3.6 Case 6 – Exhibition Hall

The exhibition hall displays old literature artifacts and its located just on top of the main entrance area, with vertical openings on the west façade. Given that there is a dome available, the lamps are turned off. However, it is recorded that they are kept on when exhibitions take place.

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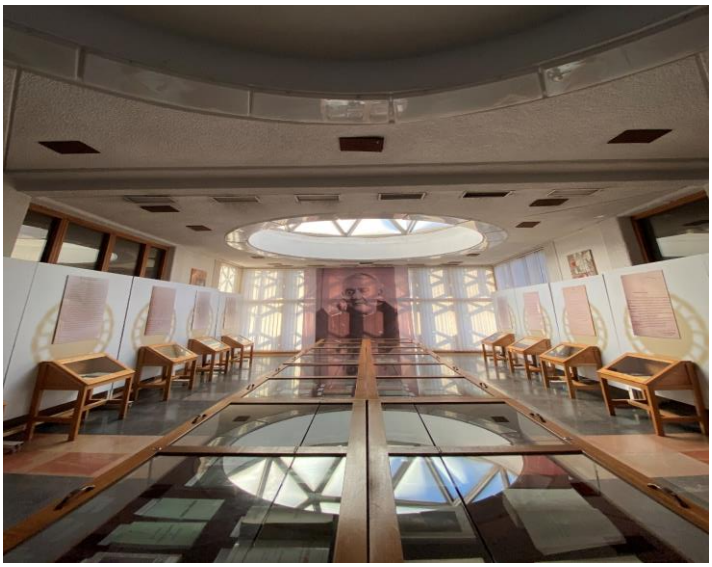

Figure 10 – Exhibition Hall

2.3.7 Case 7 – Main Reading Room

The reading rooms are the most important part of the library. NLK has two main reading rooms, which for this study will be called the main and secondary reading room. There also exists the private rooms, which are located on the last floor and will be explained on another chapter.

Figure 11 represent the main primary reading room, which can take 200 readers. The room is located on the first floor, with its windows oriented north and west.

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Figure 11 – Main Reading Room modular spaces where a dome is available

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2.3.8 Case 8 – Secondary Reading Room

As said above, the secondary room also represents one of the most important rooms of the library, and it can house 100 readers. The orientation of the vertical openings lies on the north and east façade, and there are several domes on top. The consideration regarding the spaces is the same as with the other reading room, that due to the size and the modular shape, the simplification of measuring and simulation includes the separation of spaces. In this case, namely the spaces were from Space 1 to 5, and it will be shown as such on further photos and layout plans.


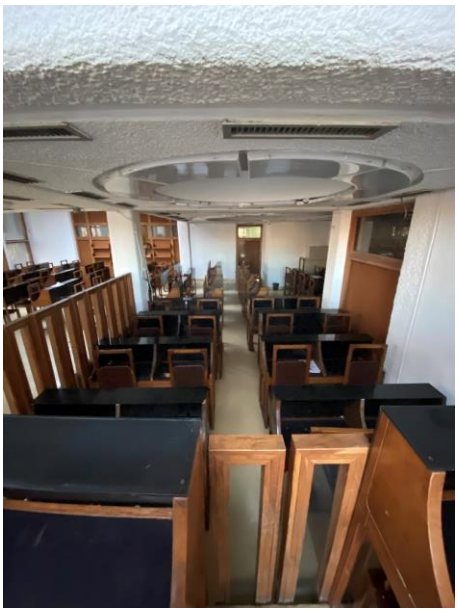

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Figure 12 – Secondary Reading Room's modular spaces

2.3.9 Case 9 – Private Reading Rooms

The private rooms, which can be regarded also as individual and/or group reading rooms, are located on the third and fourth floors of the library. Due to the shape of the building being that it narrows on higher floors, the rooms become smaller and therefore they are used for individual and/or group use. The photos and layout plans as represented on Figure 13, show the four rooms that were used for this examination. There are two rooms divided into four spaces divided with wall partitions, and the four of them share 2 domes. That means, that zenithal illumination is provided for all of them, and therefore the artificial lighting is used based on occupants' preference.

Figure 13 - Private Reading Rooms Space

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2.4 In-situ Measurement

The instruments used for the in-situ measurements are Konica Minolta LS 100 Luminance meter and the Konica Minolta T-10A Illuminance meter.

2.4.1 Konica Minolta LS 100 Luminance meter

The Konica Minolta LS 100 (Figure 14) is a spot luminance meter that provides the users with accurate measurements, even at short distances and small areas down to 0.4mm in diameter. It can measure not only immediate luminance, but also luminance ratio and peak luminance using previously recorded and saved reference values. It may be used to measure a wide variety of light sources as well as reflecting surfaces. The device features automated color correction and calibration settings, but users may also configure their own on demand. The device's single reflex lens (SLR) enables for exact measurement of the target area regardless of distance. Both the viewfinder and the external display show the measured luminance levels. The user can choose between cd/m^2 and fL as the luminance unit. The measurement range is 0.001 to 299.900 cd/m^2 (0.001 to 87.530 fL), with a precision of 2% for the first digit of the displayed result (Konica 2013).

Within the scope of this work, this device was used for measuring the luminance values (cd/m^2) of light sources and surfaces of the case study rooms.

Figure 14 - Konica Minolta LS 100 Luminance meter

(Konica Minolta 2013)

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2.4.2 Konica Minolta T-10A Illuminance meter

Konica Minolta T-10A (Figure 15) is a multi-functional digital illuminance meter that is used to measure illuminance of a specific location with the capability to express average values of illumination. Based on a reference integration time, the device may measure illuminance, illuminance difference and ratio, average illuminance, and integrated illuminance. After powering on, the instrument automatically calibrates and allows the user to choose a color correlation factor (CCF). Both continuous and intermittent light sources are available to the user. The illumination unit may be set to lx or fcd. The measurement range is 0.01 to 299.900 lx (0.01 to 29.990 fcd), with a precision of 2% for the first digit of the displayed value. The device's LCD screen can display the measurement results (Konica 2012).

Within the scope of this work, this instrument was used for measuring the horizontal illuminance (lx) and spot illuminance values (lx) inside the case study rooms of the library. Since the selected reading rooms pretty much resemble a measuring grid itself (tables and chairs distributed evenly), no measuring grid was previously determined. Rather yet, the device was put on each table, with the same distance as the previous one. The measurements were transcribed into external data and used for further illumination analysis, which will be elaborated further.

Figure 15 - Konica Minolta T-10A Illuminance meter

(Konica Minolta 2012)

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2.5 Simulation

As stated on Section 2.1, the in-situ measurements were performed during the peak of COVID-19 period, and therefore the opening hours of the library were limited for access after 16:00PM. Considering that the study encompasses the effect of daylight and the artificial lighting as well, the rest of the data is obtained via simulation. In this order, results for the evening hours were obtained. The simulation of the lighting performance of the case study rooms was performed via DIALux Evo. DIALux Evo is a lighting simulation tool that offers a wide range of applications in the field of lighting design and building automation. It has a broad catalogue of real-life luminaire products, which includes detailed technical and photometric information from various leading manufacturers. Through the luminaire search engine, namely LUMsearch (LUMsearch 2021), all luminaires in the catalogue are easily accessible and importable to DIALux Evo. Moreover, the DIALux Evo supports the file formats DWG and DXF; therefore, the target simulation area can either be imported into DIALux Evo after being drawn in a CAD tool or can be created from the beginning in DIALux Evo (DIAL GmbH 2011). In this work, 2D drawings of the case study rooms were imported into DIALux Evo and consequently illumination simulations were performed.

2.6 Survey

The purpose of this questionnaire is to assess whether the natural light coming from the overhead domes and vertical windows is sufficient for the occupants or not. The survey contains 19 questions, some of which are informational questions, the rest are ranking questions for lighting parameters. These parameters have been graded from 1 to 7, where the occupants can select between categories that indicate satisfaction or dissatisfaction regarding the illumination in the overall spaces of the building. Answers to these questions are found on Table 46 -Tabulated results for all participants and zones, found on Section 3.4.2. This survey has also enabled a better conclusion to the testing of the hypothesis of this thesis – the occupant visual perception and performance. Of particular importance is also artificial lighting which affects the occupant's visual performance in general. A more generalized data collection is presented on Appendix C, namely Survey Results Graphs.

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2.7 Lighting evaluation criteria

People can execute visual activities effectively and accurately with ample and suitable illumination, and notably more on activities that take longer to finish or are repetitious. This chapter defines illumination requirements for humans in indoor environments that fulfill the demands of persons with normal, or corrected to normal ophthalmic capacity, for better visual comfort and performance. In accordance with norms for lighting of indoor workplaces (EN 12464-1 2002), each different task and activity has its own lighting requirements, and this was respected in the evaluation of all the case study rooms. Considering that the case study rooms are not all subject to one category activity only, the activities are compiled and presented below on Table *1*, together with their respective criterions. Another point to consider is that the real-time measurements regarding the illumination were performed via the devices, and therefore the criteria was considered. For the simulation, on the other hand, DIALux Evo already has the requirements embedded and therefore it has followed them automatically. A table with the evaluation criteria taken from EN 12464-1 that was considered during this study, is presented below on Table *1*.

Table 1 – Case Study Rooms and its relevant spaces lighting criteria as per norms (Adapted from source: EN 12464-1 2002)

Ref. #	Type of task/activity area	$\bar{E}_{m,r}$ lx	U_o	R_a	R_{UGR}
6.26.1	Conference and meeting rooms	500	0.60	80	19
6.26.6	Reception Desk	300	0.60	80	22
6.26.2	Office	500	0.60	80	19
6.28.1	Entrance halls	100	0.40	80	22
6.33.1	Bookshelves	200	0.40	80	19
6.33.2	Reading area	500	0.60	80	19
6.33.3	Counters	500	0.60	80	19
6.44.4	General lighting	300	0.40	800	22
6.36.3.1	Auditorium, lecture halls	300	0.60	80	19
6.36.17	Circulation areas, corridors	100	0.40	80	25

Table Legend	
Ref.No.	Gives the actual reference number as per EN 12464-1
$\bar{E}_{m,r}$	Gives the minimum maintained illuminance on the reference surfaces for the task area
U_o	Gives the minimum illuminance uniformity on the reference surface for the maintained illuminance chosen $\bar{E}_m$
R_a	Gives the minimum color rendering indices for the situation listed in column 2
R_{UGR}	Gives the maximum UGR Limits that are applicable to the situation listed in column 2

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2.7.1 Reflectance of surfaces

The luminance of all surfaces must be considered when creating a well-balanced luminance distribution and will be determined by the reflectance of and illuminance on the surfaces. High surface reflectance contributes to energy savings and may lead to better visual comfort. Reflectance values range from 0 to 1 with zero meaning that all the incident light is absorbed and therefore the object is considered perfectly black.

Table 2 –Recommended reflectance's for the major interior diffuse surfaces (Adapted from source: EENN 12464-1 2002)

Type of surface/material	Reflectance
Ceiling	0.6 – 0.9
Walls	0.3 – 0.8
Floor	0.2 – 0.4
Furniture	0.2 – 0.7
Working Planes	0.2 – 0.6
Clear Interior Glass	0.1
Dark Wood	0.1
Dark Carpet	0.1
Light Carpet	0.4
Window Glass	0.1

2.7.2 Task area and surrounding area illuminance

The illuminance of the immediate surrounding area should be appropriate to the illuminance of the task area, and the visual field should have a well-balanced luminance distribution. Whilst the recommendations acknowledge that this may be difficult to achieve, in some complex areas it is vital that measures are taken to ensure that the correct illuminance is achieved in all areas where there is a visual task.

According to the SLL Code for Lighting, the illuminance of the immediate surrounding area shall be related to the illuminance of the task area and should provide a well-balanced luminance distribution in the visual field. The immediate surrounding area should be a band with a width of at least 0.5 m around the task area within the visual field (Raynham et al. 2012).

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Table 3 – Recommendations on the relationship of illuminances on immediate surroundings to the illuminance on the task area (Raynham et al. 2012)

Illuminance on the task area E_{task}/lx	Illuminance on immediate surrounding areas /lx
≥750	500
500	300
300	200
200	150
150	E_{task}
100	E_{task}
< 50	E_{task}

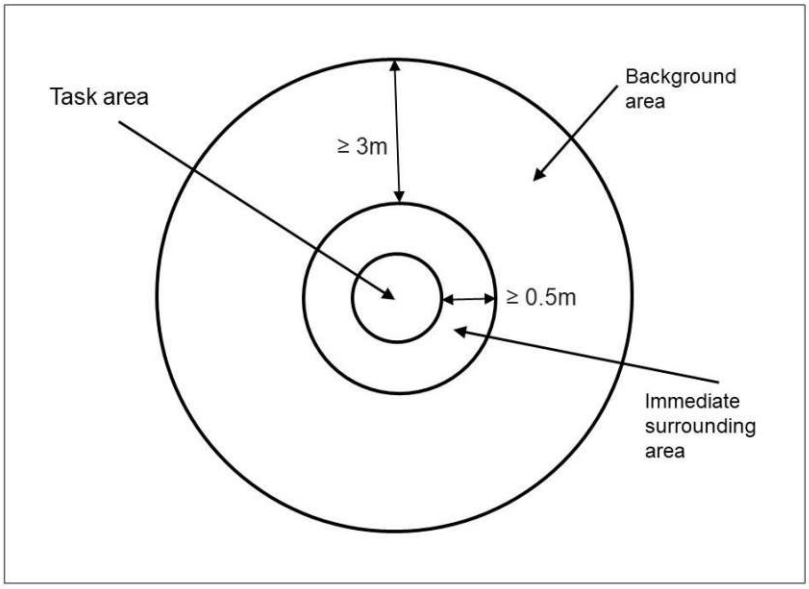

Figure 16 - Task Area, Immediate Surrounding area, and background areas distance (Raynham et al. 2012)

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2.7.3 Iluminance uniformity

In the task or activity area, the illuminance uniformity U_o shall be not less than the minimum uniformity values given in Table 4.

Table 4 – Recommendations on illuminance uniformity (Raynham et al. 2012)

	Artificial lighting or daylight opening in ceiling/roof	Vertical Daylight Openings
Immediate Surrounding Area	$U_o \geq 0{,}40$	In larger areas, activity areas, and background areas the available daylight decreases rapidly with the distance from the window. The additional benefits of daylight (see more below) can compensate for the lack of uniformity.
Background Area	$U_o \geq 0{,}10$	

Additional Benefits of Daylight

Daylight can provide all, or part of the lighting needed for visual tasks, potentially conserving energy. It also gives changeable modeling and brightness patterns and varies in level, direction, and spectral composition over time, which is considered as good for people in indoor working conditions. Windows are prominent in offices because of the natural light they give and the visual contact they provide with the outside world. It's also crucial to make sure that the windows don't cause any visual or thermal discomfort, as well as a loss of privacy.

2.7.4 Glare

As already mentioned before, glare is the sensation produced by bright areas within the visual field such as lit surfaces parts of the luminaires, windows and/or roof lights. Glare shall be limited to avoid errors fatigue and accidents. Glare can be experienced either as discomfort glare or as disability glare. In interior workplaces, disability glare is not usually a major problem if discomfort glare limits are met. Glare caused by reflections in specular surfaces is usually known as veiling reflections or reflected glare. According to EN 12464-1, there is a range of permitted glare, namely UGR_L in the table, which is followed accordingly depending on the area of activity presented. The UGR values are graded in the range of 10 ("no glare") and 30 ("unacceptable psychological glare"): 13, 16, 19, 22, 25, 28. The greater the UGR value, the greater the probability of glare. These limit values are assigned to specific activities and rooms, and they must not be exceeded (Zumtobel 2018).

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Table 5 - UGR limits that must not be exceeded (Zumtobel 2018)

	UGR limits (UGR_L)
Technical drawing	≤ 16
Reading, writing, training, meetings, computer-based work	≤ 19
Craft and light industries	≤ 22
Heavy industry	≤ 25
Railway platforms, foyers	≤ 28

2.7.5 Color rendering

For visual performance and the feeling of comfort and well-being, the colors surrounding the environment, of objects and of human skin, shall be rendered with sufficient accuracy according to the task requirements given. To provide an objective indication of the color rendering properties of a light source the general color rendering index R_a is used. The maximum value of R_a is 100. The minimum value of color rendering index for distinct types of task and activity areas within a space are given in Table 1.

2.7.6 Daylight opening recommendations

Apart from EN 12464-1, which in general is the most crucial standard to follow, there is also EN 17037 which represents the daylight in buildings recommendations. This standard encouraged building designers to assess and ensure successfully daylit spaces. It also allows building designers and developers to target ambitions with respect to daylighting, as well as addressing other issues related to daylight design, such as view out, protection against glare, and exposure to sunlight. In addition, recommendations for the duration of sunshine exposure within occupied rooms are given. This document gives information on how to use daylighting to provide lighting within interiors, and how to limit glare. Table *6* gives recommendations for daylight provision in a space.

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Table 6 - Recommendations of daylight provision by daylight openings in vertical and inclined surface (EN 17037 2019)

		Min.	Med.	High
1.1	Target Illuminance [E_T lx]	300	500	750
1.2	Minimum target illuminance [E_{TM} lx]	100	300	500
Note	Horizontal surfaces are all openings if the entire opening is above the reference plane of the space under consideration (above 0,85m).			

Assessment of daylight in interior spaces

Daylight can contribute significantly to the lighting needs of any type of building. This means that daylight openings should have appropriate areas to provide sufficient daylight throughout the year. Thus, the evaluation of daylight provision should make account of the availability of daylight at the site in addition to accounting for the properties of the space (e.g external obstruction, glazing transmittance, thickness of walls and roofs, internal partition and surface reflectance, furniture).

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3 RESULTS

3.1 Overview

In this chapter, the results of the in-situ measurements during the day and the simulation data for the evening (with artificial lighting) is presented. The daytime measurements include the ones conducted via the devices such as the illuminance and luminance on surfaces. The luminance results retrieved from the device, were put in an equation to conclude the reflectance of the relevant surfaces. Since the in-situ measurements could not be conducted at evening nights due to limited working hours, a simulation was performed to retrieve the results for the artificial lighting during those hours. Apart from retrieving the illuminance values for evening hours, the simulation was also used to obtain the glare for the daylight hours.

According to sub-chapter 2.7.2, the task area and the surrounding area illumination are important when considering the results. Since this study will entail different types of case study rooms, some rooms will not have consideration of the relationship between the task area and surrounding area and instead they will be regarded generally via an average illumination and not via a measuring grid. For example, due to the shape of the library, most spaces of the reading rooms are different in geometry i.e., there are separated spaces, corners, and secluded spaces and therefore they have been treated as modules. As such, they will be examined separately and elaborated for each relevant chapter, summarizing the result in the end, and compared with the EN-12464 guidelines. The measuring grid in this study will be used for the evening measurements i.e., the simulations, as the measurement grid is automatically determined via the software. The grids are presented on Appendix A-Measuring Grids.

Lastly, a summary report for each case study comparing the actual results with the lighting recommendations will be elaborated. Each case study will have a recommendation on an improvement scenario, if considered necessary. Lastly, the survey results will be thoroughly presented to showcase the occupant's satisfaction. In the last chapter, all the presented results will be summarized and compared to showcase proper reading of the results.

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3.2 In-situ Measurement Results

3.2.1 Daytime Results

Entrance Hall - Reception and Lounge Area

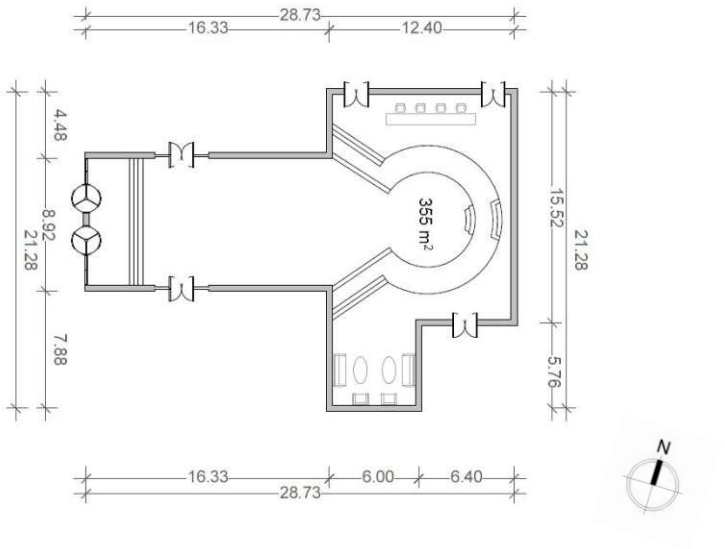

Figure 17 – Entrance Hall Layout Plan

Table 7 – Entrance Hall; Room conditions recorded before measuring

Date	05.01.2021
Measurement Time	14:00-15:00PM
Weather	10 ° C
Sky Condition	Overcast Sky
Vertical Openings	No
Dome Availability	Yes
Artificial Lights	Off

Table 8 – Entrance Hall; Average daylight illumination results

Average Illuminance E_{avg} [lx]	855
Minimum Illuminance E_{min} [lx]	570
Uniformity [U_o]	0.66
$UGR_{simulated}$	<10

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Table 9 – Entrance Hall; Reflectance of major surfaces

Object	Material	Reflectance [%]
Floor	Sandstone Tiles	23
Ceiling	White Plaster	21
Walls	White Plaster	22

Administration Office

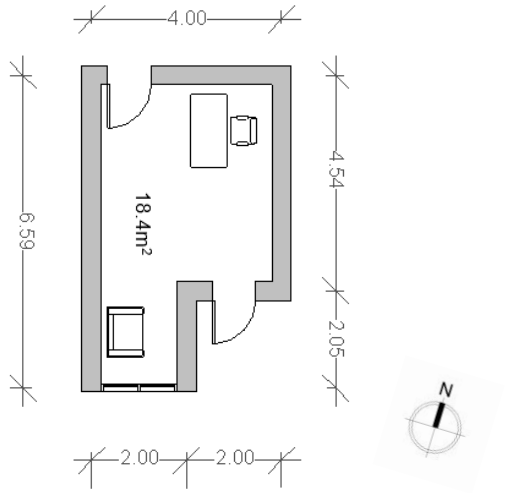

Figure 18 - Administration Office Layout Plan

Table 10 - Administration Office; Room conditions recorded before measuring

Date	06.01.2021
Measurement Time	11:00-12:00PM
Weather	12 °C
Sky Condition	Overcast Sky
Vertical Openings	Yes
Dome Availability	Yes
Artificial Lights	Off

Table 11 – Administration Office; Average daylight illumination results

Average Illuminance E_{avg} [lx]	1411
Minimum Illuminance E_{min} [lx]	900
Uniformity [U_o]	0.63
$UGR_{simulated}$	<10

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Table 12 – Administration Office; Reflectance of major surfaces

Object	Material	Reflectance [%]
Floor	Red Carpet	4
Ceiling	White Plaster	15
Walls	White Plaster	14

Conference Room

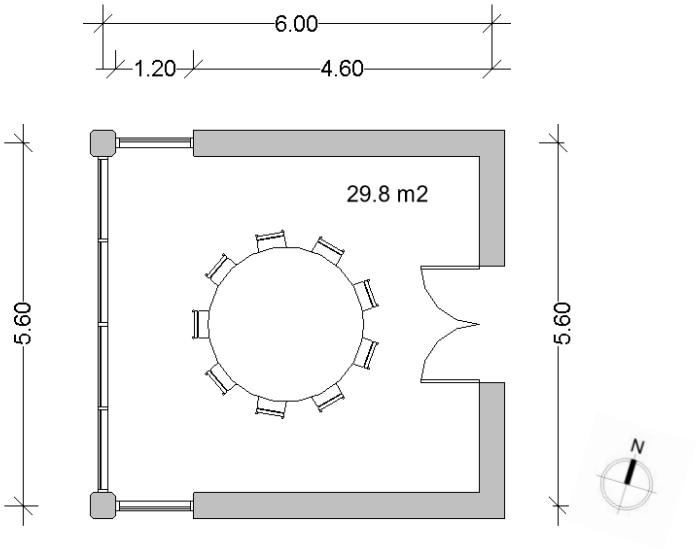

Figure 19 - Conference Room Layout Plan

Table 13 – Conference Room; Room conditions recorded before measuring

Date	06.01.2021
Measurement Time	12:00-13:00PM
Weather	12 °C
Sky Condition	Overcast Sky
Vertical Openings	Yes
Dome Availability	Yes
Artificial Lights	Off

Table 14 – Conference Room; Average daylight illumination results

Average Illuminance E_{avg} [lx]	590
Minimum Illuminance E_{min} [lx]	465
Uniformity [U_o]	0.78
$UGR_{simulated}$	18.3

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Table 15 – Conference Room; Reflectance of major surfaces

Object	Material	Reflectance [%]
Floor	Green Carpet	8
Ceiling	White Plaster	22
Walls	Wood Partition	31

Auditorium

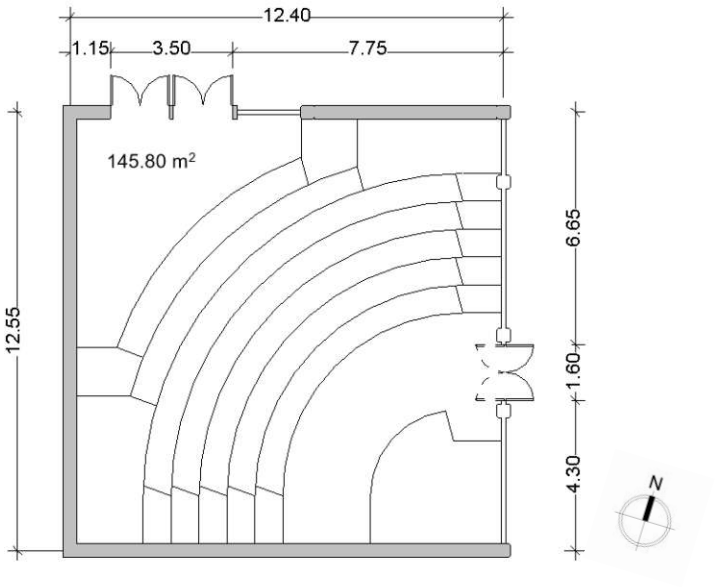

Figure 20 - Auditorium Layout Plan

Table 16 – Auditorium; Room conditions recorded before measuring

Date	06.01.2021
Measurement Time	12:20-12:50PM
Weather	12 ° C
Sky Condition	Overcast Sky
Vertical Openings	No
Dome Availability	Yes
Artificial Lights	Off

Table 17 – Auditorium; Average daylight illumination results

Average Illuminance E_{avg} [lx]	1908
Minimum Illuminance E_{min} [lx]	166
Uniformity [U_o]	0.10
$UGR_{simulated}$	18.2

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Table 18 – Auditorium; Reflectance of major surfaces

Object	Material	Reflectance [%]
Floor	Beige Carpet	24
Ceiling	White Plaster	77
Walls	Dark Wood	10

Book Club Room

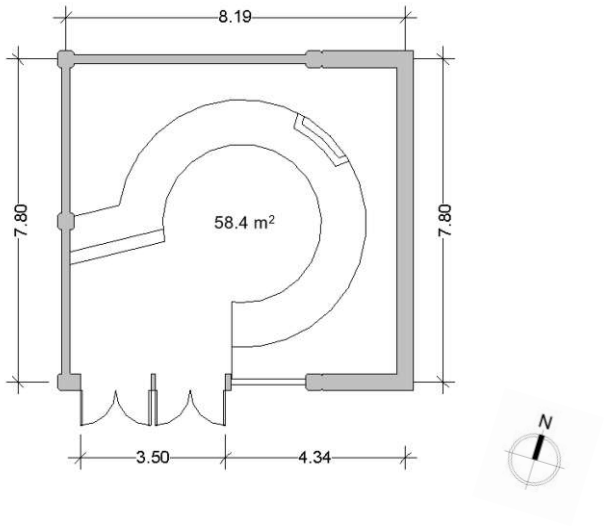

Figure 21 - Book Club Room Layout Plan

Table 19 – Book Club Room; Room conditions recorded before measuring

Date	06.01.2021
Measurement Time	11:20-11:40PM
Weather	12 °C
Sky Condition	Overcast Sky
Room Orientation	South-West
Vertical Openings	No
Dome Availability	Yes
Artificial Lights	Off

Table 20 – Book Club Room; Average daylight illumination results

Average Illuminance E_{avg} [lx]	630
Minimum Illuminance E_{min} [lx]	411
Uniformity [U_o]	0.65
$UGR_{simulated}$	18

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Table 21 – Book Club Room; Reflectance of major surfaces

Object	Material	Reflectance [%]
Floor	Beige Carpet	35
Ceiling	White Plaster	69
Walls	Dark Wood	8

Exhibition Hall

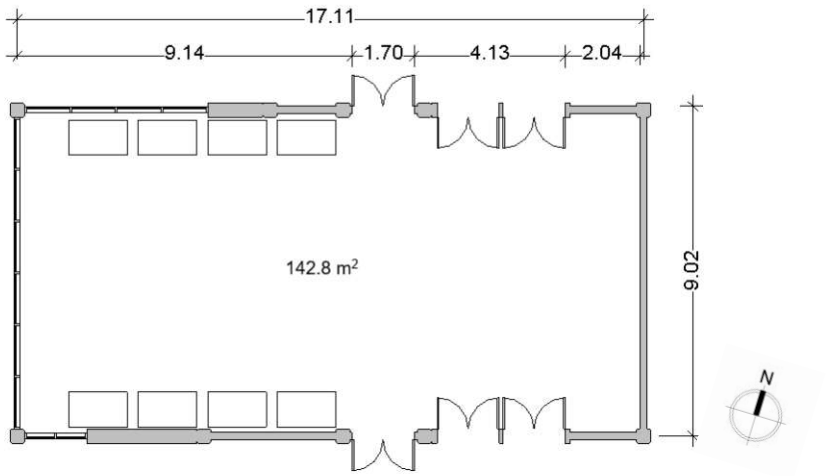

Figure 22 - Exhibition Hall Layout Plan

Table 22 – Exhibition Hall; Room conditions recorded before measuring

Date	05.01.2021
Measurement Time	15:30PM
Weather	12 °C
Sky Condition	Overcast Sky
Vertical Openings	Yes
Dome Availability	Yes
Artificial Lights	Off

Table 23 – Exhibition Hall; Average daylight illumination results

Average Illuminance E_{avg} [lx]	780
Minimum Illuminance E_{min} [lx]	106
Uniformity [U_o]	0.13
$UGR_{simulated}$	10

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Table 24 – Exhibition Hall; Reflectance of major surfaces

Object	Material	Reflectance [%]
Floor	Marble Floor	14
Ceiling	White Plaster	43
Walls	Dark Wood	17

Main Reading Room

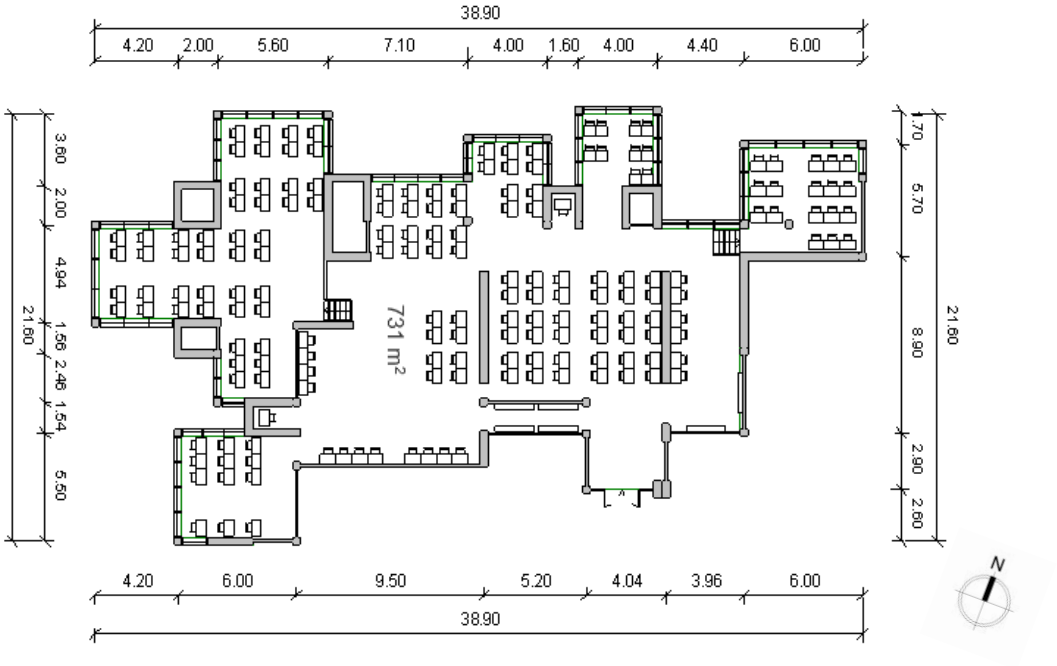

Figure 23 - Main Reading Room Layout Plan

Table 25 – Main Reading Room; Room conditions before measuring

Date	06.01.2021
Measurement Time	13:20-14:30PM
Weather	12 °C
Sky Condition	Overcast Sky
Vertical Openings	Yes
Dome Availability	Yes
Artificial Lights	Off

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Table 26 – Main Reading Room; Average daylight illumination results

	Average Illuminance E_{avg} [lx]	Minimum Illuminance E_{min} [lx]	Uniformity [U_o]	UGR simulated
Zone 1	1200	253	0.21	<10
Zone 2	903	190	0.21	<10
Zone 3	560	236	0.42	18.6
Zone 4	470	152	0.32	20
Zone 5	985	217	0.22	22.6
Zone 6	1995	416	0.20	17.9
Zone 7	1400	175	0.12	17.3
Mean	**1073**	**-**	**0.24**	**16.6**

Table 27– Main Reading Room; Reflectance of major surfaces

Object	Material	Reflectance [%]
Floor	Linoleum Beige	28
Ceiling	White Plaster	68
Walls	White Plaster	50
Workplane	Notebook	17

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Secondary Reading Room

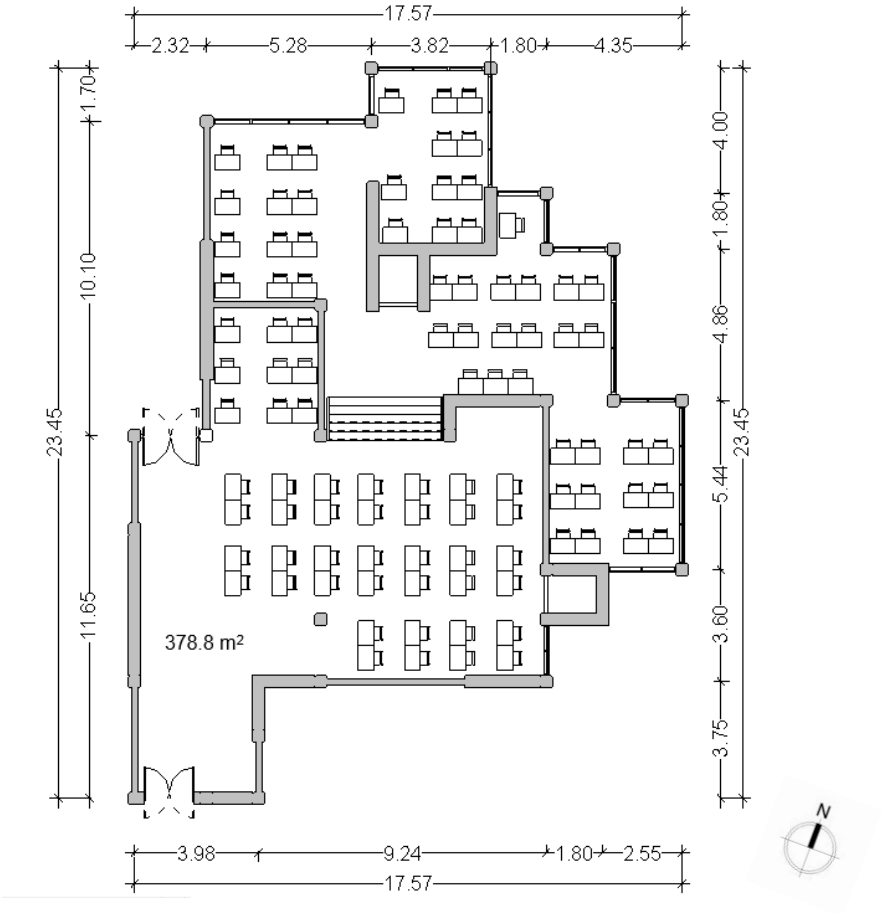

Figure 24 -Secondary Reading Room Layout Plan

Table 28 – Secondary Reading Room; Room conditions before measuring

Date	06.01.2021
Measurement Time	13:20-14:30PM
Weather	12 ° C
Sky Condition	Overcast Sky
Vertical Openings	Yes
Dome Availability	Yes
Artificial Lights	Off

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Table 29– Secondary Reading Room; Average daylight illumination results

Zone Name	Average Illuminance E_{avg} [lx]	Minimum Illuminance E_{min} [lx]	Uniformity [U_o]	UGR simulated
Zone 1	109	228	0.10	20.2
Zone 2	980	236	0.24	<10
Zone 3	560	236	0.42	18.6
Zone 4	254	50	0.20	<10
Zone 5	135	85	0.62	<10
Mean	**407**	**-**	**0.31**	**13.7**

Table 30 – Secondary Reading Room; Reflectance of major surfaces

Object	Material	Reflectance [%]
Floor	Linoleum Beige	61
Ceiling	White Plaster	69
Walls	White Plaster	86

Private Reading Rooms

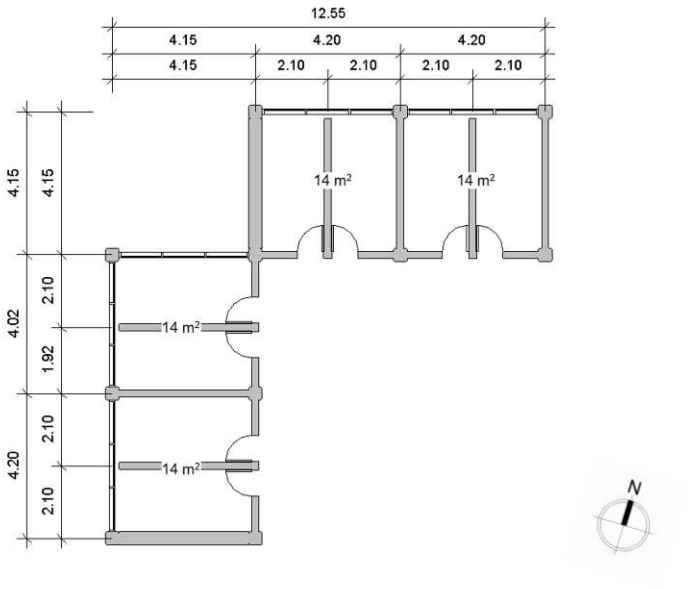

Figure 25- Private Reading Rooms Layout Plan

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Table 31 – Private Reading Rooms; Room conditions recorded before measuring

Date	05.01.2021
Measurement Time	15:30-16:10PM
Weather	12 ° C
Sky Condition	Overcast Sky
Vertical Openings	Yes
Dome Availability	Yes
Artificial Lights	Off

Table 32 – Private Reading Rooms; Average daylight illumination results

Zone Name	Average Illuminance E_{avg} [lx]	Uniformity [U_o]	UGR simulated
Zone 1	820	0.85	<10
Zone 2	820	0.11	<10
Zone 3	757	0.13	<10
Zone 4	757	0.13	<10
Zone 5	377	0.82	<10
Zone 6	365	0.96	<10
Zone 7	292	0.76	<10
Zone 8	280	0.84	<10
Mean	**558**	**0.54**	**10**

Table 33 – Private Reading Rooms; Reflectance of major surfaces

Object	Material	Reflectance [%]
Floor	Green Carpet	5
Ceiling	White Plaster	80
Walls	White Plaster	84

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3.2.2 Daytime Summary Results – All Rooms

Table 34 presents a summarized results for daylight illumination, conducted via the devices during on-site measurements. The UGR was simulated afterwards via DIALux.

Table 34 – Daytime summary results table

	Room Name	Average Illuminance E_{avg} [lx]	Uniformity [U_o]	UGR simulated
1	Entrance Hall	855	0.66	<10
2	Admin. Office	1411	0.63	<10
3	Conference Room	590	0.78	18.3
4	Auditorium	1908	0.10	18.2
5	Exhibition Hall	780	0.13	10
6	Book Club Room	630	0.65	18
7	Main Reading Room	1073	0.24	16.6
8	Secondary Reading Room	407	0.31	13.7
9	Private Reading Rooms	558	0.54	10

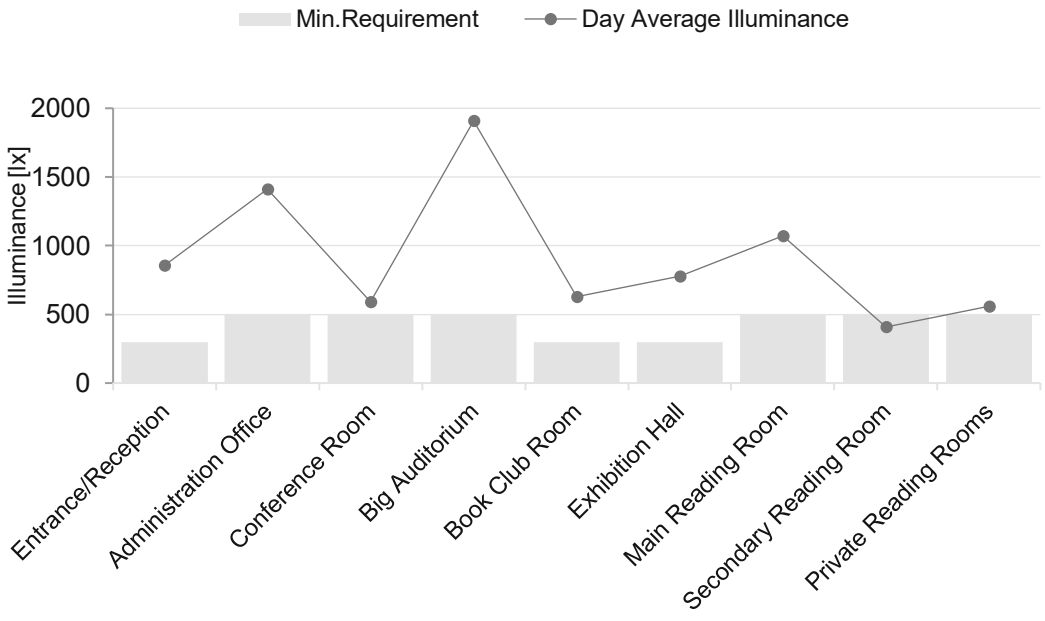

Figure 26 – Daytime Measured Average Illuminance vs Standard

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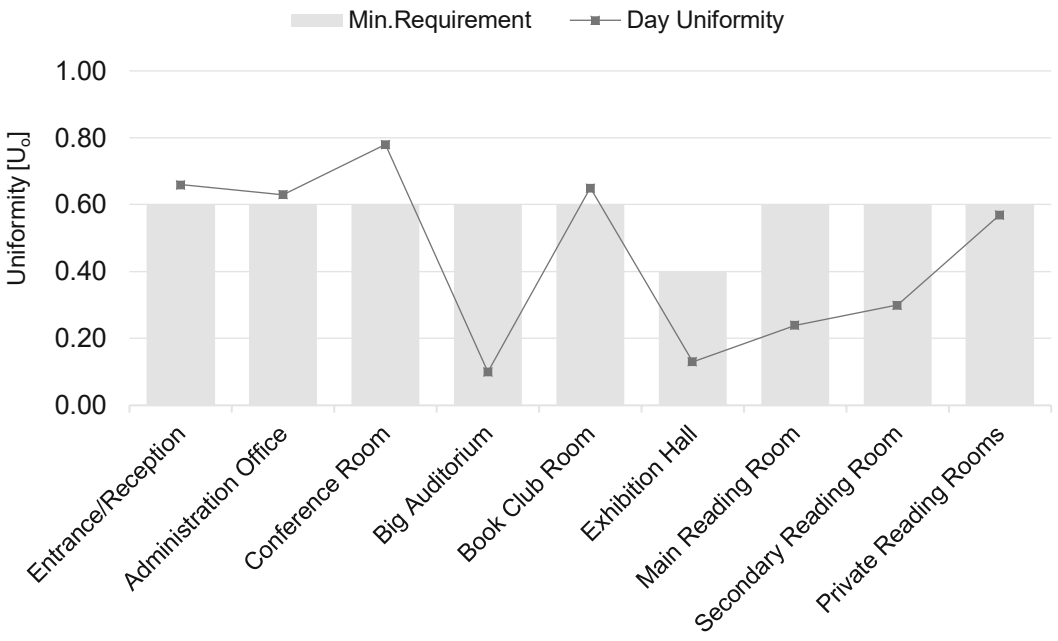

Figure 27 – Daytime Measured Uniformity vs Standard

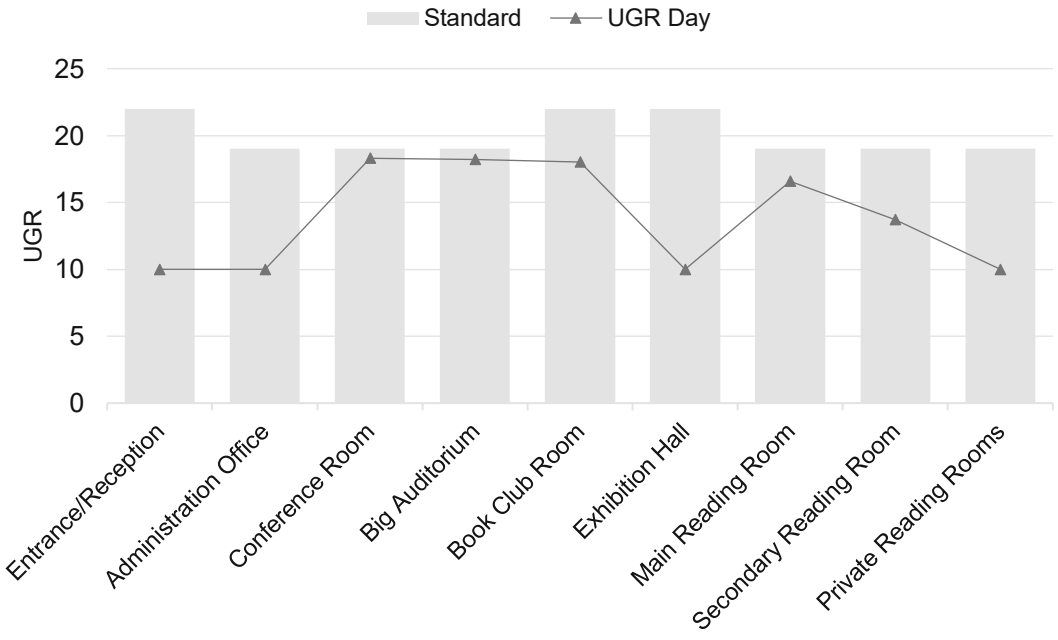

Figure 28 - Daytime Measured UGR vs Standard

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3.3 Simulation Results

The following tables represent all data collected from simulation, for each corresponding zone of the case studies. Due to bigger size of certain areas, the rooms were divided into zones – for a more accurate data collection.

3.3.1 Evening Results

Entrance Hall

Table 35 – Entrance Hall Reception Area; Simulation results

	Reception Area
Average Illuminance E_{avg} [lx]	398
Illuminance on immediate surrounding areas $E_{surround}$ [lx]	391
Overall Average Illuminance E_{avg} [lx]	448
Uniformity [U_o]	0.56
UGR	14.6

Table 36 – Entrance Hall Lounge Area: Simulation Results

	Lounge Area
Average Illuminance E_{avg} [lx]	536
Illuminance on immediate surrounding areas $E_{surround}$ [lx]	581
Overall Average Illuminance E_{avg} [lx]	608
Uniformity [U_o]	0.85
UGR	14.7

Administration Office

Table 37 – Administration Office; Simulation results

Average Illuminance E_{avg} [lx]	513
Illuminance on immediate surrounding areas $E_{surround}$ [lx]	450
Overall Average Illuminance E_{avg} [lx]	456
Uniformity [U_o]	0.26
UGR	17.5

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Conference Room

Table 38 – Conference Room; Simulation results

Average Illuminance E_{avg} [lx]	340
Illuminance on immediate surrounding areas $E_{surround}$ [lx]	240
Overall Average Illuminance E_{avg} [lx]	276
Uniformity [U_o]	0.41
UGR	24.9

Auditorium

Table 39 – Auditorium; Simulation results

Average Illuminance E_{avg} [lx]	212
Illuminance on immediate surrounding areas $E_{surround}$ [lx]	153
Overall Average Illuminance E_{avg} [lx]	184
Uniformity [U_o]	0.45
UGR	23.3

Book Club Room

Table 40 – Book Club Room; Simulation results

Average Illuminance E_{avg} [lx]	157
Illuminance on immediate surrounding areas $E_{surround}$ [lx]	115
Overall Average Illuminance E_{avg} [lx]	131
Uniformity [U_o]	0.49
UGR	20.9

Exhibition Hall

Table 41 – Exhibition Hall; Simulation results

Average Illuminance E_{avg} [lx]	263
Illuminance on immediate surrounding areas $E_{surround}$ [lx]	285
Overall Average Illuminance E_{avg} [lx]	275
Uniformity [U_o]	0.32
UGR	20.6

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Main Reading Room

Table 42 – Main Reading Room; Simulation results summary for all zones

Zone Name	Illuminance on the task area E_{task} [lx]	Illuminance on immediate surrounding areas $E_{surround}$ [lx]	Overall Average Illuminance E_{avg} [lx]	Uniformity [U_o]	UGR
Zone 1	157	235	188	0.32	16.2
Zone 2	165	96	116	0.23	21
Zone 3	207	246	227	0.37	14.7
Zone 4	156	160	158	0.71	13.1
Zone 5	148	182	165	0.40	19.6
Zone 6	227	271	236	0.36	19.2
Zone 7	212	274	236	0.36	19.2
Mean	**189**	**-**	**-**	**0.39**	**17.5**

Secondary Reading Room

Same as with the previous case study, the secondary reading room also constitutes for one of the biggest and most important spaces in the building. Due to the variety of shapes on the different spaces of this room, the spaces are divided similarly to the previous chapter.

The overall room will be spread in spaces and accordingly each space will have its own results reading, constituting to a summary result chapter in the end. In total, the room will have 5 examined spaces. The layout plan with the highlighted spaces is seen below on Table *43*.

Table 43 – Secondary Reading Room; Simulation results summary for all zones

Zone Name	Illuminance on the task area E_{task} [lx]	Illuminance on immediate surrounding areas $E_{surround}$ [lx]	Overall Average Illuminance E_{avg} [lx]	Uniformity [U_o]	UGR
Zone 1	154	188	163	0.14	22.7
Zone 2	151	140	149	0.49	19.2
Zone 3	107	-	107	0.29	15.8
Zone 4	154	-	154	0.49	19.4
Zone 5	103	-	103	0.39	18.4
Mean	**135**	**-**	**-**	**0.36**	**19**

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Private Reading Rooms

The last rooms to have been examined are the private reading rooms on the last floor of the library. In reality, the rooms contain space for 2-3 people and so they can also be used for grouping learning spaces. Due to maintenance works, only 4 spaces are currently available for the readers and thus 4 spaces are examined and presented in the upcoming chapters.

Table 44 – Private Reading Rooms; Simulation results summary for all zones

Zone Name	Illuminance on the task area E_{task} [lx]	Illuminance on immediate surrounding areas $E_{surround}$ [lx]	Overall Average Illuminance E_{avg} [lx]	Uniformity [U_o]	UGR
Zone 1	279	272	278	0.69	14.3
Zone 2	384	365	374	0.61	11
Zone 3	377	360	368	0.64	11
Zone 4	395	372	374	0.62	11
Zone 5	365	358	346	0.71	12.3
Zone 6	368	363	349	0.70	12.2
Zone 7	361	354	355	0.70	12.2
Zone 8	367	362	363	0.73	12
Mean	**351**	**-**	**-**	**0.68**	**12**

3.3.2 Evening Summary Results – All Rooms

Table 45 presents a summarized simulation results for evening illumination, conducted via DIALux Evo.

Table 45 – Evening summary results table for all case studies

#	Room Name	Average Illuminance E_{avg} [lx]	Uniformity [U_o]	UGR simulated
1	Entrance Hall	528	0.70	14.6
2	Admin. Office	456	0.26	17.5
3	Conference Room	276	0.41	24.9
4	Auditorium	184	0.45	23.3
5	Book Club Room	131	0.49	20.6
6	Exhibition Hall	275	0.32	20.6
7	Main Reading Room	189	0.39	17.5
8	Secondary Reading Room	135	0.36	19
9	Private Reading Rooms	351	0.68	12

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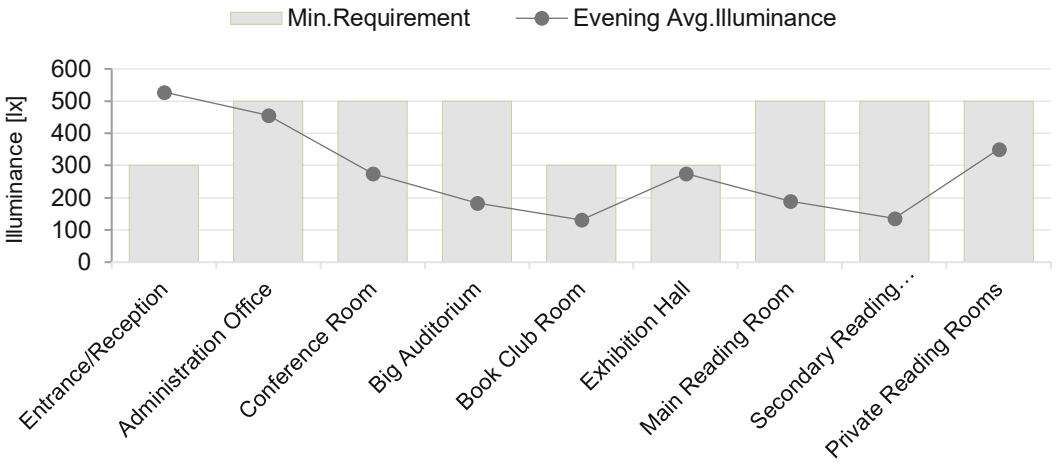

Figure 29 - Evening Simulated Average Illuminance vs Standard

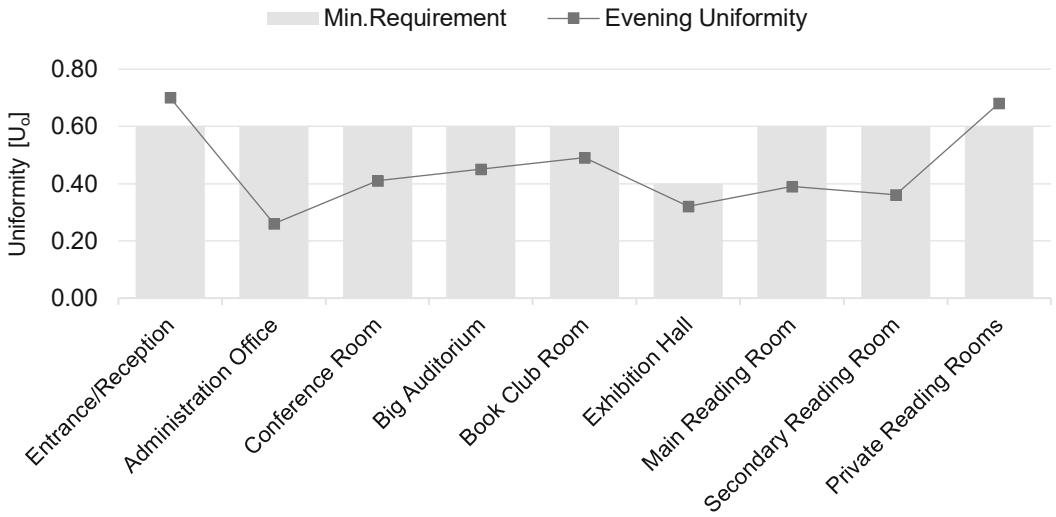

Figure 30 - Evening Simulated Uniformity vs Standard

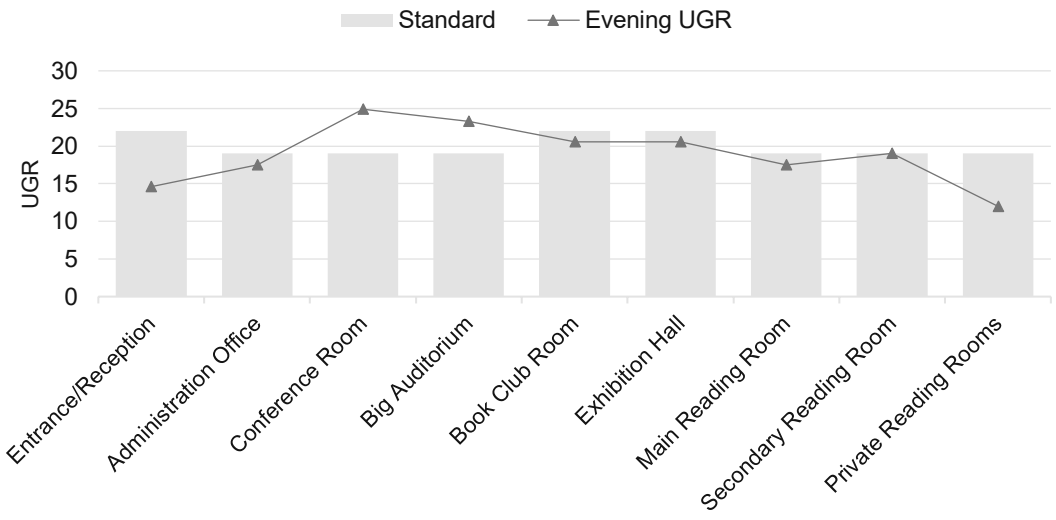

Figure 31 - Evening Simulated UGR vs Standard

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3.4 Survey Results

3.4.1 General information

The conducted survey gathered 32 participants, out of which 17 were females and 15 males. 78% of the participants were found in the group age below 30 years old. 41% of the participants reported that they spend 7-8 hours per day in the building, out of which 72% of them use the library for reading purposes. The survey also reports that 41% of the participants uses glasses while performing their activities.

3.4.2 Survey findings

According to the data collected, out of 32 participants, 66% of the surveys were recorded in the reading room (21 people), 19% in the reception area (6 people) and 16% (5 people) within the administration offices. Table 46 below presents the results in a tabulated form. The rating is consequently explained on the rating legend.

Table 46 -Tabulated results for all participants and zones

	Rating						
Visual Comfort	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Visual comfort from natural light only	8	4	8	6	3	1	2
Visual comfort from artificial light only	3	3	7	4	5	9	1
Desk lamp preferred	0	0	0	2	2	10	18
Rate Light							
a) Visual Task Area	4	2	12	9	3	2	0
b) The overall room	5	6	4	9	6	2	0
c) In front of the PC	7	3	7	7	7	1	0
Visual Satisfaction							
a) Illumination at morning	8	12	6	2	1	2	1
b) Illumination in the afternoon	4	6	12	5	1	4	0
c) Illumination at night	2	2	7	2	8	6	5
Visual Sensation							
Experience brightness (glare)	12	10	3	3	4	1	0
Experience gloomy dark sensation	5	4	4	7	8	3	1
Comfortability with the current lighting system	6	4	4	8	6	4	0
Rating Legend							
1 Completely Satisfied							
2 Satisfied							
3 Fairly Satisfied							
4 Neutral							
5 Fairly Dissatisfied							
6 Dissatisfied							
7 Completely Dissatisfied							

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3.5 Improvement Proposal

As mentioned previously, the library is currently using traditional mercury-vapor lamps, which consequently influence the uniform distribution of light in the overall spaces and moreover help on the general increase of the energy consumption of the building. According to the results obtained both from the daytime measurements and the evening simulation, it can be concluded that the current lighting fixtures are not providing enough illumination – especially for the evening hours. Therefore, the improvement proposal for all cases is the change of lighting fixtures. For all the cases, the new lighting fixture is presented on Figure 32 - .

PHILIPS Slim Blend Rectangular, Surface Mounted

- SM402C POE W31L125 1 xLED42S/840
- Total Lamp Flux: 4200 lm
- Luminous Flux: 4200 lm
- Power: 35 W
- L x B x H: 1.25 x 0.31 x 0.07m

SM402C POE W31L125 1 xLED42S/840

1 x 4200 lm

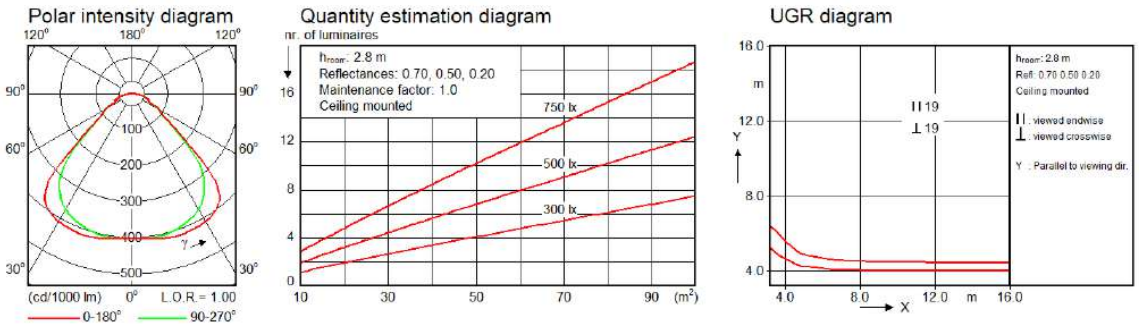

Figure 32 - PHILIPS Slim Blend Lamp (LUMSearch 2021)

After inputting the lighting system as per Figure 32 above, the simulation was done for both daytime and evening hours, however considering that the improvement was mostly required for the evening hours, the improvement results for the evening hours is tabulated and presented below in Table 47 and 48.

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Table 47 – Evening Hours Average Illuminance; Before and After

Average Illuminance E_{avg} [lx]				EN 12464-1
#	Case Study Room	Before	After	
1	Entrance Hall	528	772	100
2	Administration Office	456	711	500
3	Conference Room	276	540	500
4	Auditorium	184	322	300
5	Book Club Room	131	446	300
6	Exhibition Hall	275	600	300
7	Main Reading Room	190	743	500
8	Secondary Reading Room	135	550	500
9	Private Reading Room	351	708	500

Table 48 – Evening Hours UGR; Before and After

UGR				EN 12464-1
#	Case Study Room	Before	After	
1	Entrance Hall	14.6	10.6	22
2	Administration Office	17.5	17	19
3	Conference Room	24.9	13	19
4	Auditorium	23.3	20	19
5	Book Club Room	20.6	18	22
6	Exhibition Hall	20.6	17.5	22
7	Main Reading Room	17.5	17	19
8	Secondary Reading Room	19	15.6	19
9	Private Reading Room	12	12.7	19

The results show that the replacement of the lighting system from mercury-vapor lamp to LED lamps show an improvement in the illumination, uniformity and the UGR of each respective case study room. As such, it can be concluded that the lighting recommendation as per EN 12464-1 are fulfilled.

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4 COMPARISON AND DISCUSSION

4.1.1 Overview

This chapter compares the daytime in-situ measurements and the simulation results for the evening, with the respective EN 12464-1 norms. After elaborating an improvement proposal, the improved effect will also be reflected to showcase a before-after scenario and to cross-check whether the proposal will be effective into meeting the lighting recommendations. Moreover, an overview of the survey results that reflects the occupant's visual perception of each study room examined within the library will be presented. Based on the result overview, further elaboration will be made.

- **Entrance Hall - Reception and Lounge Area**

As presented on Table 8, the daytime measurements obtained in-situ via the illumination devices show that the minimum lighting requirements are already met for the category of entrance halls. The same can be concluded from Table 35 and Table 36 Table *45* for the evening hours as well. Although the illumination norms have been met, an improvement proposal was insisted regardless, considering that the library uses old fashioned mercury-vapor lamps. The corresponding change has shown further improvement, as presented on Table 47 and Table 48.

- **Administration Office**

Given that the room is oriented on the south, results showed that during the day the domes and the windows provide enough illumination so that the user does not need to turn the artificial lighting throughout the day after all. The evening measurements, on the other hand, although close to the minimum requirement, show that the uniformity of light is rather low. Considering that the lighting system is positioned right underneath the dome, and the office has an L-Shape, it is understandable that the light is not distributed uniformly. As such, the improvement proposal has shown effective change.

- **Conference Room**

It is observed that the minimum requirements for the illumination have been met during the day, however during the evening the illumination is rather low.

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Although practically the conference table is not used any time after 17:00PM, the change of luminaires has shown that the average illuminance has shifted from 276 lx to 540 lx, whereas the UGR rating has improved from 25 to 13.

- **Auditorium**

Records show that the daylight provision without the use of the artificial lighting is meeting the minimum requirements, however the uniformity is far below the minimum requirement. That means that the illumination is not scattered uniformly and therefore some audience members will perceive lower illumination levels and thus influence their visual capacity. The improvement has shown effective change of illuminance, uniformity, and reduction in the UGR levels.

- **Book Club Room**

Although this room is regarded as the least frequented room of the whole library, measurements show that the daylight coming from the dome provides enough illumination, uniformity and decent UGR rating. The improvement proposal has shifted the evening illumination from 131 lx to 446 lx, whereas the UGR has improved from 20.6 to 17.5.

- **Exhibition Hall**

The minimum requirement set for this case study room is taken from the standard for trade fairs and exhibition halls and the results show that the minimum requirements were met during the day, however the light is not distributed uniformly. The reason behind this lies behind the artificial lighting turned off during the time when measurements took place. If we assume that the artificial lighting is turned on during the day, the uniformity would have been met. The improvement proposal shows exactly that, where the illumination has improved from 275 lx to 600 lx.

- **Main Reading Room**

Given that the design of the reading rooms is shaped in open-air modules, the reading room was divided into several spaces and concluded into an average by the end. The overall generalized result show that the availability of multiple domes and the windows (given the orientation of the reading room being north-west) are effective into providing adequate daylight provision during the day, without the need to turn off the artificial lighting. During the night however, the average illuminance of the whole room is 190 lx, and as such constituting to very dark areas. The same response can be recorded on the survey results as per Table 71.

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- **Secondary Reading Room**

Given the orientation of the secondary reading room (north-east), some parts of the room are not well lit. As such, the daylight measurements show lower illuminance values, especially in the areas where no dome nor window is available in proximity to the reading desks. The same can be applied for the evening hours, where the average illuminance was recorded at 135 lx. The improvement proposal has increased the average illuminance to 550 lx and the UGR from 19 to 15.6.

- **Private Reading Rooms**

The results obtained from the on-site measurements during the day show that the average illuminance, uniformity and the UGR all meet the minimum requirement. The orientation of the rooms is on the north-west and all rooms have available domes and windows. The same cannot be recorded for simulation for evening hours, where after the improvement proposal the average illuminance has increased from 351 lx to 708 lx.

4.1.2 Result Summary - Illumination

Figure 33 and Figure 34 represent a generalized overview of the obtained illumination results before and after the improvement proposal.

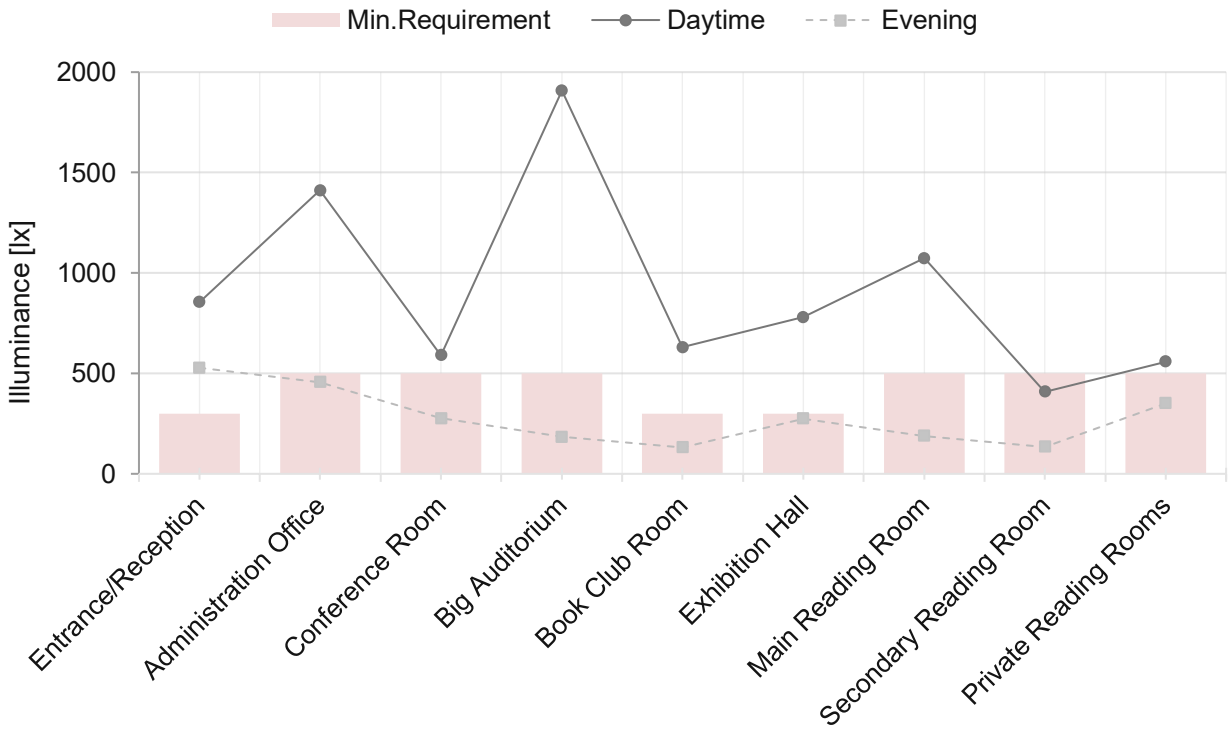

Figure 33 – Average Illuminance; Before

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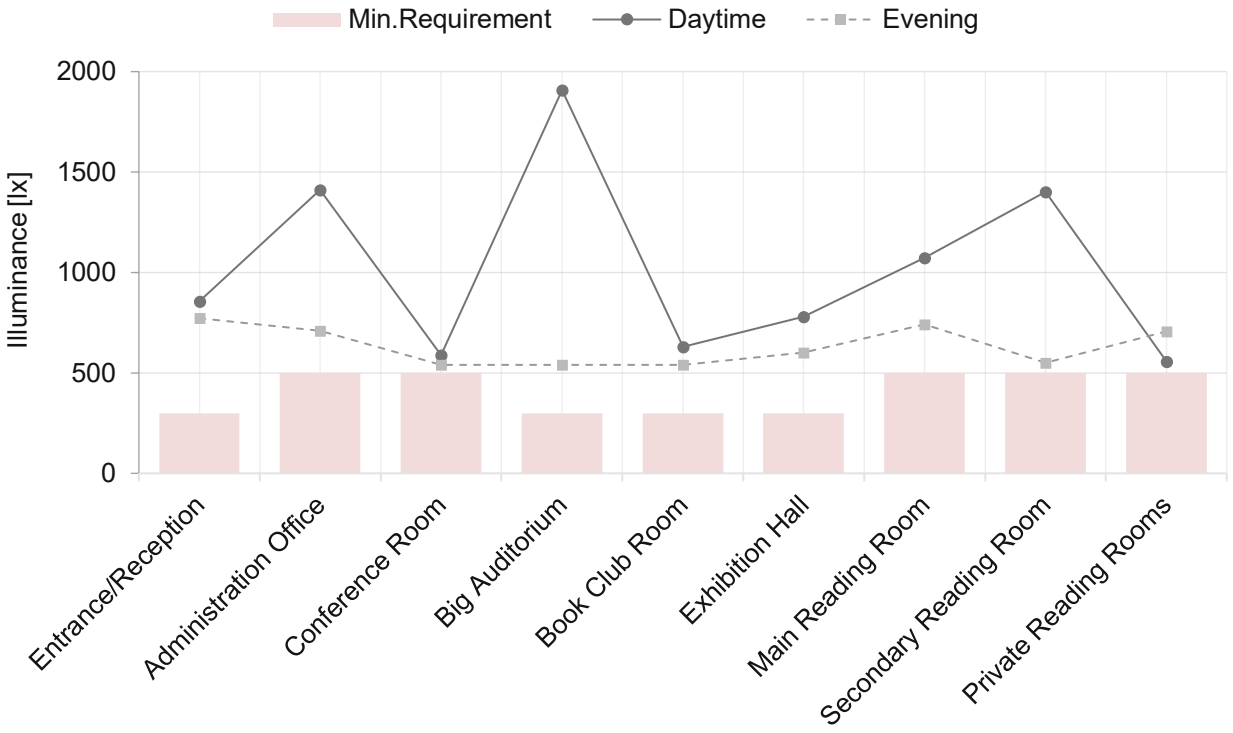
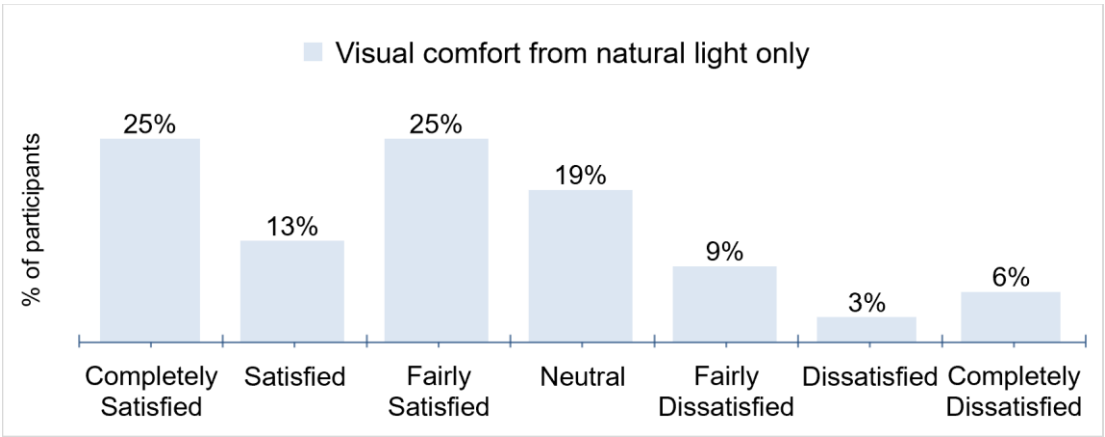


Figure 34 - Average Illuminance; After

4.1.3 Result Summary – Survey

Apart from the illumination observations made in-situ via the lx devices and the following simulation afterwards, the survey was a big component which required careful observation and elaboration. As seen on Section 3.4.2, the results have been summarized to showcase responses for the areas where the survey was filled out. The plots shown on Figure 35 represent the most important outcome regarding the visual perception of the main occupants of the library and a broader result visualization that captures each question of the survey more carefully can be found on Appendix C- Survey Results Graphs.



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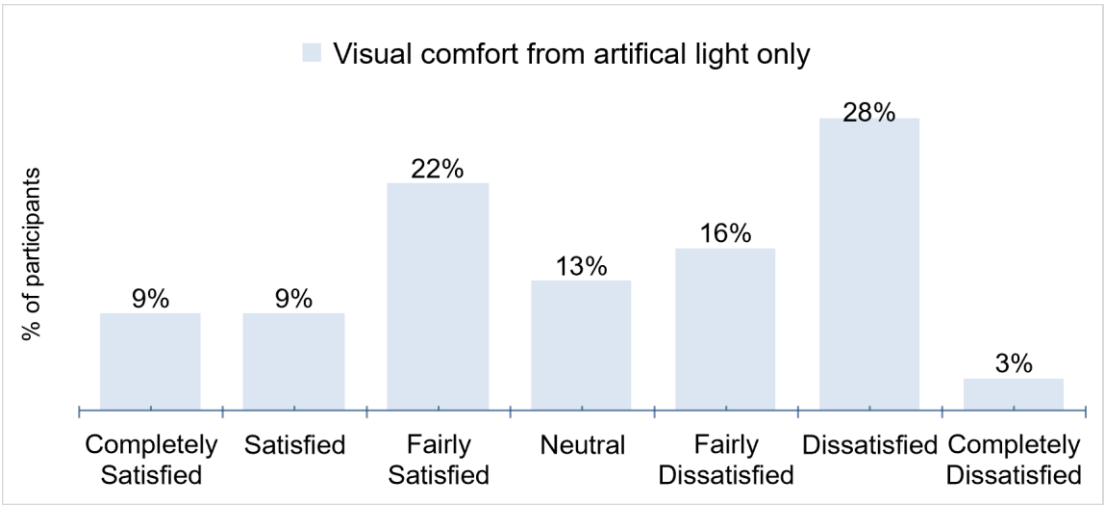

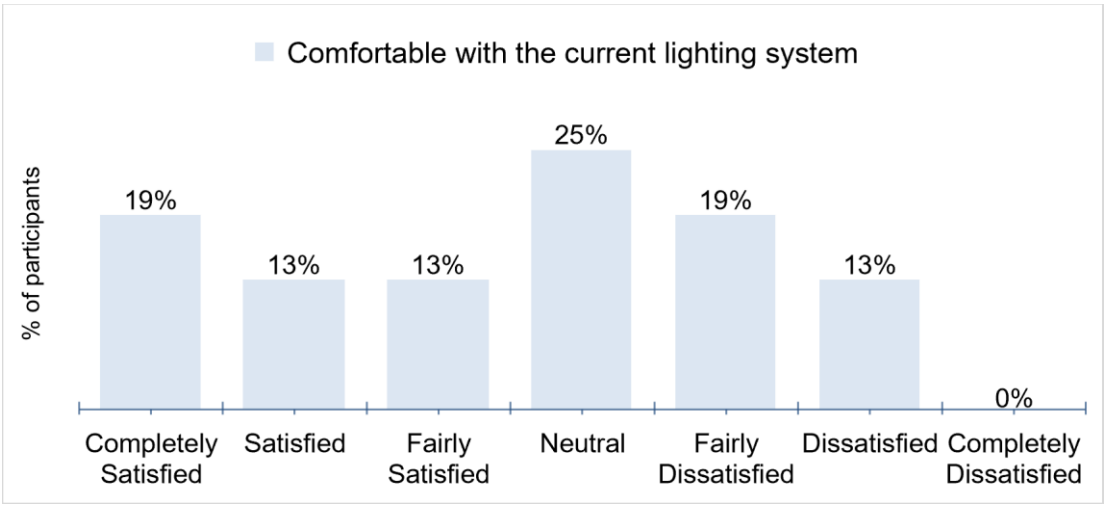

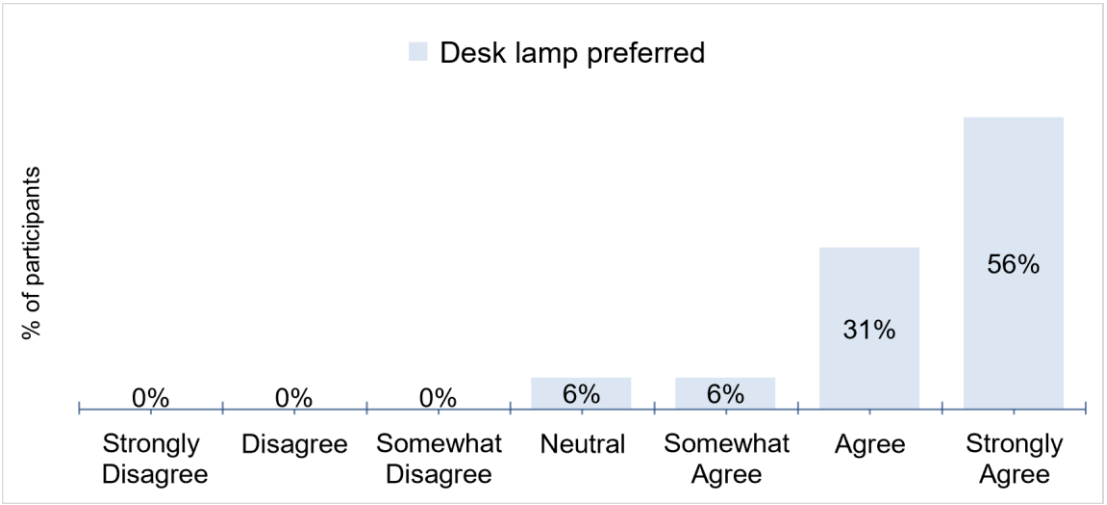

Figure 35 – Survey Results

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5 CONCLUSION

This study examined the present situation of illumination in the NLK library and investigated further how the availability of domes and the abundant windows have contributed to the overall daylight provision within the most important spaces of the building. Within the framework of this thesis, nine case study rooms were considered and analyzed by means of in-situ measurements via the illumination devices. In absence of evening measurements due to working hours limitations from COVID-19, the simulation was conducted to evaluate further if the current artificial lighting system is meeting the minimum requirements as per the norms. The evaluations consist of not only the illuminance analysis, but also different indicators such as uniformity, unified glare rating (UGR) and the reflectance of surfaces. Considering that the visual comfort plays a major role in the overall performance of a building, a survey was distributed to the users of the library. To finish, an improvement scenario was provided for each case study room that required attention.

It is also noted that in order to obtain the maximum possible accuracy during the on-site measurements, the only person in the room during measurements was the evaluator, and that the artificial lighting was switched off. Calibration setting mistakes that may have happened during measurements, on the other hand, should always be taken into account. As a result of this possibility, applying the derived luminance and illuminance values to the reflection formula may have resulted in inaccurate surface reflectance values. Furthermore, because these numbers were further inserted to DIALux for the lighting simulation of each room, the overall simulation results may be misleading. As a result, neither the in-situ measurements nor the simulation findings should be regarded at face value, and an error margin should always be factored in.

According to the results obtained, it can be considered – as expected – that the illumination in the rooms during daytime fulfill the minimum lighting requirement. There is, however, certain areas (corners) of each case study rooms where the light does not distribute uniformly and considering that the artificial lighting was turned off during the time of measurement, it can be assumed that the combination of both (while also considering that the improvement proposal takes place) would improve the overall uniform light distribution. The simulation can also have its own shortcomings. An important one to mention is that DIALux does not support designing nor importing of complex shapes of a building.

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More particularly, the domes in the ceiling cannot be imported nor designed in the program, and as such the model was simplified to showcase a ceiling opening with material input i.e., manual reflection value of the dome acryl glass inserted. It can therefore be expected that simulation results do have less accuracy in the areas where the effect of daylight might not be considered. It is safe, however, to mention that in this particular situation, the simulation procedure was conducted for the evening hours – meaning that the daylight provision was disabled anyhow.

The findings from simulation via DIALux Evo show that without exception, all case study rooms had less illumination than recommended during the evening hours. This outcome was expected, given that the library is currently using old school mercury-vapor lamps as luminaires and the importance of the applicability of lighting standards in small-scale settings. It is also valuable to mention again the previous study from KAF, where the illumination during the night was identified as a main concern, and this work has backed up just that.

The optimizations conducted in the framework of this study showed that the replacement of luminaires from mercury vapor lamps to new LED luminaires have improved the overall illuminance performance on all case study rooms, in particularly during the evening hours. This adjustment has moreover improved the UGR rating, which is considered very important for reading spaces.

To wrap up the examination, the conducted survey has shown a variety of responses from the occupants. According to the results, the occupants have stated that the daylight provision supplied solely by the domes and the vertical openings provides sufficient comfort. During the evening times, however, when the daylight is disabled, the occupants state that they feel fairly dissatisfied with the light levels. It is also recorded that in absence of task lamps on the reading room, about 87% of the occupants agree that an available desk lamp would be preferable. From this, a very important point to consider for further improvement of the library in general, is the definite need to add desk lamps into the reading rooms.

Despite having numerous lighting calculations and simulation methods to achieve the gained results, further research questions are necessary in the direction of tackling the energy consumption of the overall building, especially considering the current situation where the library still uses mercury vapor lamps.

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6 INDEX

6.1 List of Abbreviations

NLK National Library of Kosovo

KAF Kosovo Architecture Foundation

Lm Lumen

Fc Footcandle

Fcd Femtocandela

ρ Reflectance

Φ Luminous Flux

I Luminous Intensity

E Illuminance

L Luminance

U_o Uniformity

UGR Unified Glare Rating

DF Daylight Factor

$\bar{E}_m$ Maintained Illuminance

E_{avg} Average Illuminance

E_{min} Minimum Illuminance

$E_{surround}$ Illuminance on the Immediate Surrounding Areas

E_{task} Illuminance on the Visual Task

R_a Color Rendering Index

E_T lx Target Illumination

E_{TM} lx Minimum Target Illumination

CEN European Committee for Standardization

ISO International Organization for Standardization

CIE International Commission on Illumination

SLL Society of Light and Lighting

SLR Single Reflex Lens

CCF Color Correlation Factor

LED Light Emitting Diode

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6.2 List of Figures

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6.3 List of Tables

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6.4 List of Equations

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8 APPENDICES

A. Measuring Grids

Entrance Hall - Reception and Lounge Area

Table 49 - Reception Area; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6
A	o	o	o	o	o	o
B	o	o	o	o	o	o
C	o	o	o	o	o	o
D	o	o	o	o	o	o
E	o	o	o	o	o	o
F	o	o	o	o	o	o
G	o	o	o	o	o	o
H	o	o	o	o	o	o
I	o	o	o	o	o	o
J	o	o	o	o	o	o

	1	2	3	4	5	6
A	346	354	378	384	391	392
B	334	377	389	393	398	400
C	373	385	392	400	403	407
D	354	388	399	403	405	412
E	380	390	404	404	413	412
F	369	388	402	409	412	415
G	380	393	406	410	414	415
H	366	391	405	409	418	419
I	352	381	406	408	418	420
J	351	362	389	407	420	427

Table 50 – Lounge Area; Visual task (blue) and Immediate Surrounding Area (grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8
A	o	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o	o
F	o	o	o	o	o	o	o	o
G	o	o	o	o	o	o	o	o
H	o	o	o	o	o	o	o	o

	1	2	3	4	5	6	7	8
A	525	521	542	541	529	521	486	467
B	560	567	574	571	554	552	531	486
C	583	596	613	609	568	576	566	542
D	585	606	623	624	618	599	589	530
E	577	597	625	617	598	609	565	525
F	563	580	606	597	595	570	558	435
G	626	566	575	570	585	556	527	430
H	510	524	532	530	520	522	476	466

Administration Office

Table 51 - Administration Office; Visual task (dark light grey) and Immediate Surrounding Area (grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8	9
A	o	o	o	o	o	o			
B	o	o	o	o	o	o			
C	o	o	o	o	o	o			
D	o	o	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o	o	o

	1	2	3	4	5	6	7	8	9
A	417	471	521	536	514	462			
B	448	535	591	602	581	514			
C	483	547	612	626	591	511			
D	405	522	578	593	551	451	327	213	143
E	371	464	513	526	483	411	306	223	153

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Conference Room

Table 52 – Conference Room; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7
A	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o
F	o	o	o	o	o	o	o
G	o	o	o	o	o	o	o
H	o	o	o	o	o	o	o

	1	2	3	4	5	6	7
A	143	187	220	230	219	189	149
B	194	250	290	301	287	247	194
C	241	303	341	353	309	298	236
D	268	333	363	373	363	327	261
E	273	340	366	377	368	292	267
F	258	316	353	364	351	313	252
G	218	277	316	326	308	272	217
H	175	223	252	268	255	218	177

Auditorium

Table 53 – Auditorium; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8	9	10	11
A	o	o	o	o	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o	o	o	o	o
F	o	o	o	o	o	o	o	o	o	o	o
G	o	o	o	o	o	o	o	o	o	o	o
H	o	o	o	o	o	o	o	o	o	o	o
I	o	o	o	o	o	o	o	o	o	o	o
J	o	o	o	o	o	o	o	o	o	o	o
K	o	o	o	o	o	o	o	o	o	o	o

	1	2	3	4	5	6	7	8	9	10	11
A	102	120	146	164	174	177	173	163	143	117	100
B	120	152	177	195	205	209	205	194	175	151	119
C	145	176	200	216	222	225	222	215	199	173	141
D	160	193	215	225	227	228	228	226	214	190	156
E	170	202	221	228	227	225	227	229	222	199	167
F	171	203	223	227	225	224	225	229	221	201	168
G	167	199	220	227	227	226	227	227	217	197	163
H	155	187	210	222	227	227	227	221	208	184	152
I	134	166	192	209	215	217	216	207	187	164	132
J	113	142	164	183	195	198	193	181	161	139	111
K	94	110	131	150	159	161	159	148	129	111	92

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Book Club Room

Table 54–Book Club Room; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8
A	o	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o	o
F	o	o	o	o	o	o	o	o
G	o	o	o	o	o	o	o	o
H	o	o	o	o	o	o	o	o
I	o	o	o	o	o	o	o	o

	1	2	3	4	5	6	7	8
A	76	91	102	110	113	106	94	80
B	92	112	128	135	177	132	118	98
C	107	134	132	151	159	139	140	115
D	120	144	162	171	173	167	152	128
E	96	113	169	177	180	175	130	105
F	122	147	169	180	187	174	151	138
G	114	139	159	170	172	163	149	130
H	97	120	135	149	192	144	130	114
I	80	99	113	122	124	116	104	91

Exhibition Hall

Table 55 – Exhibition Hall; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8	9	10
A	o	o	o	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o	o	o	o
F	o	o	o	o	o	o	o	o	o	o
G	o	o	o	o	o	o	o	o	o	o
H	o	o	o	o	o	o	o	o	o	o
I	o	o	o	o	o	o	o	o	o	o
J	o	o	o	o	o	o	o	o	o	o
K	o	o	o	o	o	o	o	o	o	o
L	o	o	o	o	o	o	o	o	o	o
M	o	o	o	o	o	o	o	o	o	o
N	o	o	o	o	o	o	o	o	o	o
O	o	o	o	o	o	o	o	o	o	o
P	o	o	o	o	o	o	o	o	o	o
Q	o	o	o	o	o	o	o	o	o	o
R	o	o	o	o	o	o	o	o	o	o
S	o	o	o	o	o	o	o	o	o	o
T	o	o	o	o	o	o	o	o	o	o
U	o	o	o	o	o	o	o	o	o	o
V	o	o	o	o	o	o	o	o	o	o

	1	2	3	4	5	6	7	8	9	10
A	210	225	238	258	250	252	253	239	228	217
B	237	249	262	270	277	274	262	254	246	242
C	252	265	287	302	307	299	305	284	271	252
D	275	297	324	329	341	345	324	315	300	272
E	292	313	320	344	349	351	356	338	316	294
F	300	322	353	345	397	359	359	342	328	309
G	304	325	355	356	393	355	353	346	327	304
H	303	325	354	352	396	360	351	333	325	298
I	293	314	317	346	352	345	340	331	310	283
J	273	285	315	329	342	340	330	314	288	273
K	252	271	299	310	326	325	318	297	274	281
L	247	268	282	311	319	308	301	295	265	233
M	225	259	281	298	311	311	297	279	265	233
N	238	256	283	301	315	314	299	287	256	234
O	237	267	286	305	309	311	308	293	272	243
P	235	272	285	298	303	308	300	305	277	247
Q	204	247	276	285	266	291	293	232	280	246
R	187	229	259	273	276	279	285	282	263	232
S	160	206	240	258	268	270	267	257	241	219
T	141	178	211	234	245	245	243	224	204	178
U	128	148	174	195	210	210	204	187	154	129
V	99	120	137	152	162	164	160	145	124	104

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Main Reading Room

Table 56 – Main Reading Room Space 1; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8
A	o	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o	o
F	o	o	o	o	o	o	o	o
G	o	o	o	o	o	o	o	o
H	o	o	o	o	o	o	o	o

	1	2	3	4	5	6	7	8
A	129	72	150	135	138	196	171	201
B	152	77	102	133	175	208	181	215
C	174	84	225	147	229	223	217	225
D	183	97	227	154	235	233	234	239
E	205	233	259	273	284	282	271	247
F	188	161	245	200	271	201	247	239
G	138	73	149	110	160	95	220	211
H	118	63	120	106	128	87	190	177

Table 57 – Main Reading Room Space 2; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8	9
A	o	o	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o	o	o
F	o	o	o	o	o	o	o	o	o
G	o	o	o	o	o	o	o	o	o
H	o	o	o	o	o	o	o	o	o
I	o	o	o	o	o	o	o	o	o
J	o	o	o	o	o	o	o	o	o
K	o	o	o	o	o	o	o	o	o

	1	2	3	4	5	6	7	8	9
A	29	43	48	57	57	56	56	53	54
B	37	51	58	64	70	69	64	62	60
C	50	64	79	89	94	96	87	76	70
D	77	97	117	133	140	138	119	99	75
E	108	129	158	174	178	173	157	127	94
F	113	153	176	187	106	187	175	151	112
G	120	16	160	177	144	168	148	160	122
H	122	158	176	171	155	167	172	160	124
I	112	148	170	175	169	171	169	150	114
J	96	129	150	166	166	165	150	131	96
K	76	100	120	136	138	137	117	102	77

Table 58 – Main Reading Room Space 3; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7
A	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o
F	o	o	o	o	o	o	o
G	o	o	o	o	o	o	o

	1	2	3	4	5	6	7
A	174	221	173	242	240	123	222
B	193	239	190	264	265	144	243
C	225	260	263	279	277	267	254
D	223	248	275	281	274	266	236
E	219	241	254	269	262	245	224
F	193	230	200	244	242	233	211
G	161	206	182	215	215	205	191

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Table 59 – Main Reading Room Space 4; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8
A	o	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o	o
F	o	o	o	o	o	o	o	o

	1	2	3	4	5	6	7	8
A	124	140	150	158	164	162	149	132
B	82	152	98	174	185	117	115	90
C	148	182	188	192	192	180	165	145
D	153	171	188	197	152	190	165	142
E	149	170	178	188	185	167	153	131
F	145	165	175	175	169	159	146	128

Table 60 – Main Reading Room Space 4; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8	9	10	11
A	o	o	o	o	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o	o	o	o	o
E							o	o	o	o	o
F							o	o	o	o	o
G							o	o	o	o	o

	1	2	3	4	5	6	7	8	9	10	11
A	128	153	165	162	164	163	166	155	150	126	85
B	146	183	201	199	195	199	200	194	166	166	126
C	148	191	208	211	211	218	214	213	206	182	118
D	127	162	103	188	196	212	217	222	210	187	154
E							210	208	191	168	122
F							176	172	153	134	95
G							103	98	112	100	89

Table 61 – Main Reading Room Space 5; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8	9	10	11
A	o	o	o	o	o	o	o	o			
B	o	o	o	o	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o	o			
E					o	o	o	o			
F					o	o	o	o			
G					o	o	o	o			
H					o	o	o	o			
I					o	o	o	o			

	1	2	3	4	5	6	7	8	9	10	11
A	135	107	212	246	273	267	239	213			
B	141	217	220	255	300	303	292	281	287	264	24
C	171	222	224	270	283	302	304	288	303	276	252
D	152	187	209	228	264	308	310	285	287	254	201
E					292	299	296	268			
F					259	279	275	242			
G					161	242	253	205			
H					130	188	221	159			
I					107	145	175	125			

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Table 62 – Main Reading Room Space 6; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7
A	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o
F	o	o	o	o	o	o	o
G	o	o	o	o	o	o	o
H	o	o	o	o	o	o	o

	1	2	3	4	5	6	7
A	184	211	261	280	277	266	254
B	231	253	283	299	381	298	273
C	255	224	300	313	312	302	289
D	175	151	233	319	323	308	192
E	223	266	292	308	309	304	276
F	146	188	226	288	287	277	194
G	184	215	239	255	253	243	204
H	125	152	402	215	215	199	141

Secondary Reading Room

Table 63 – Secondary Reading Room Space 1; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8	9	10
A					o	o	o	o	o	o
B					o	o	o	o	o	o
C					o	o	o	o	o	o
D					o	o	o	o	o	o
E					o	o	o	o	o	o
F					o	o	o	o	o	o
G	o	o	o	o	o	o	o	o	o	o
H	o	o	o	o	o	o	o	o	o	o
I	o	o	o	o	o	o	o	o	o	o
J					o	o	o	o	o	o
K					o	o	o	o	o	o

	1	2	3	4	5	6	7	8	9	10
A					88	90	103	97	103	82
B					116	113	135	119	138	101
C					146	165	175	177	175	148
D					167	194	217	212	207	173
E					181	211	223	231	218	181
F					179	181	224	194	224	189
G	38	50	70	139	178	172	218	182	224	192
H	36	56	90	136	183	212	231	229	229	187
I	33	46	66	130	180	214	228	229	212	165
J					168	206	225	222	198	152
K					143	180	196	193	170	130

Table 64 – Secondary Reading Room Space 2; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8
A	o	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o	o
F	o	o	o	o	o	o	o	o
G	o	o	o	o	o	o	o	o

	1	2	3	4	5	6	7	8
A	104	121	135	143	145	138	126	110
B	119	140	156	167	168	162	146	127
C	98	155	124	185	145	179	134	139
D	122	163	154	195	174	188	154	148
E	125	159	167	192	184	185	155	142
F	124	148	166	178	179	171	155	132
G	73	129	101	155	122	149	115	117

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Table 65 – Secondary Reading Room Space 3; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8
A	o	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o	o

	1	2	3	4	5	6	7	8
A	39	100	74	123	113	108	92	68
B	59	114	98	140	137	122	102	77
C	94	120	136	147	143	128	107	84
D	94	117	134	144	141	125	104	83
E	43	107	122	130	118	115	98	73

Table 66 – Secondary Reading Room Space 4; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8	9
A				o	o	o	o	o	o
B				o	o	o	o	o	o
C				o	o	o	o	o	o
D	o	o	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o	o	o
F				o	o	o	o	o	o
G				o	o	o	o	o	o
H				o	o	o	o	o	o

	1	2	3	4	5	6	7	8	9
A				87	127	105	132	121	104
B				117	156	140	163	149	127
C				153	181	184	151	180	156
D	87	114	146	123	196	153	211	193	189
E	92	120	147	147	202	176	218	199	194
F				178	193	202	211	175	186
G				107	174	136	190	151	185
H				95	148	122	155	148	131

Table 67 – Secondary Reading Room Space 5; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7	8
A	o	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o	o
E	o	o	o	o	o	o	o	o
F	o	o	o	o	o	o	o	o

	1	2	3	4	5	6	7	8
A	68	37	95	97	106	101	90	78
B	78	66	11	118	129	123	81	92
C	87	94	136	135	145	136	108	101
D	90	111	131	144	147	141	126	106
E	87	49	125	133	141	136	69	102
F	80	56	114	119	126	121	73	93

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Private Reading Rooms

Table 68 – Private Reading Rooms Space 1 (left) & Space 2 (right); Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6
A	o	o	o	o	o	o
B	o	o	o	o	o	o
C	o	o	o	o	o	o
D	o	o	o	o	o	o
E	o	o	o	o	o	o
F	o	o	o	o	o	o
G	o	o	o	o	o	o
H	o	o	o	o	o	o
I	o	o	o	o	o	o
J	o	o	o	o	o	o
K	o	o	o	o	o	o
L	o	o	o	o	o	o
M	o	o	o	o	o	o

	1	2	3	4	5	6
A	o	o	o	o	o	o
B	o	o	o	o	o	o
C	o	o	o	o	o	o
D	o	o	o	o	o	o
E	o	o	o	o	o	o
F	o	o	o	o	o	o
G	o	o	o	o	o	o
H	o	o	o	o	o	o
I	o	o	o	o	o	o
J	o	o	o	o	o	o
K	o	o	o	o	o	o
L	o	o	o	o	o	o
M	o	o	o	o	o	o

	1	2	3	4	5	6
A	231	246	246	225	210	197
B	236	263	275	275	251	228
C	251	277	295	256	285	260
D	264	296	310	229	310	284
E	273	302	322	332	328	295
F	275	305	335	345	331	299
G	286	317	340	345	329	310
H	280	305	341	337	330	304
I	272	288	325	324	313	297
J	251	285	308	302	296	273
K	237	261	277	196	270	248
L	219	243	254	252	233	221
M	201	210	210	208	218	189

	1	2	3	4	5	6
A	263	281	295	321	331	315
B	303	332	351	362	366	337
C	338	371	387	402	384	357
D	354	405	383	441	422	393
E	388	429	412	449	425	404
F	396	436	448	482	440	406
G	401	433	458	456	443	398
H	402	435	458	441	428	391
I	386	427	414	428	404	376
J	377	405	317	396	377	349
K	352	380	325	364	350	327
L	322	345	317	322	313	304
M	280	307	272	278	267	260

Table 69 – Private Reading Rooms Space 3 (left) & Space 4 (right); Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6
A	o	o	o	o	o	o
B	o	o	o	o	o	o
C	o	o	o	o	o	o
D	o	o	o	o	o	o
E	o	o	o	o	o	o
F	o	o	o	o	o	o
G	o	o	o	o	o	o
H	o	o	o	o	o	o
I	o	o	o	o	o	o
J	o	o	o	o	o	o
K	o	o	o	o	o	o
L	o	o	o	o	o	o
M	o	o	o	o	o	o

	1	2	3	4	5	6
A	o	o	o	o	o	o
B	o	o	o	o	o	o
C	o	o	o	o	o	o
D	o	o	o	o	o	o
E	o	o	o	o	o	o
F	o	o	o	o	o	o
G	o	o	o	o	o	o
H	o	o	o	o	o	o
I	o	o	o	o	o	o
J	o	o	o	o	o	o
K	o	o	o	o	o	o
L	o	o	o	o	o	o
M	o	o	o	o	o	o

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	1	2	3	4	5	6
A	309	336	335	311	287	259
B	335	364	373	356	330	306
C	358	388	397	380	375	339
D	371	409	410	382	404	368
E	386	427	464	424	420	390
F	383	433	447	452	436	395
G	389	423	445	449	437	398
H	386	417	445	440	428	385
I	366	404	420	422	412	377
J	345	383	390	380	381	348
K	321	348	362	329	336	313
L	295	314	322	313	301	281
M	258	262	276	273	266	245

	1	2	3	4	5	6
A	265	285	305	327	338	316
B	306	336	357	364	371	341
C	345	378	388	399	392	368
D	374	401	385	427	406	381
E	395	422	411	440	420	392
F	409	437	457	448	425	405
G	411	441	462	485	436	404
H	400	439	455	495	428	393
I	386	428	437	441	420	389
J	371	409	416	426	408	370
K	350	381	367	392	375	343
L	326	339	322	354	347	320
M	285	300	307	313	305	291

Table 70 – Private Reading Rooms Space 5 to 8; Visual task (dark grey) and Immediate Surrounding Area (light grey) illumination results via measurement grid

	1	2	3	4	5	6	7
A	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o

	1	2	3	4	5	6	7
A	304	344	360	386	373	356	327
B	302	364	381	406	415	391	343
C	335	369	404	420	425	376	321
D	300	337	372	384	373	338	282

	1	2	3	4	5	6	7
A	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o

	1	2	3	4	5	6	7
A	306	340	376	396	383	351	290
B	322	368	407	431	426	392	329
C	311	365	403	420	420	391	348
D	299	336	359	373	379	356	329

	1	2	3	4	5	6	7
A	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o

	1	2	3	4	5	6	7
A	294	328	352	367	366	349	320
B	298	360	377	413	413	388	341
C	319	365	401	421	409	386	316
D	292	340	365	382	376	339	282

	1	2	3	4	5	6	7
A	o	o	o	o	o	o	o
B	o	o	o	o	o	o	o
C	o	o	o	o	o	o	o
D	o	o	o	o	o	o	o

	1	2	3	4	5	6	7
A	298	342	378	395	384	356	293
B	319	367	412	427	423	390	324
C	304	366	383	419	412	390	357
D	304	324	361	379	384	354	331

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B. Survey Template

QUESTIONNAIRE

1) Gender

Female ☐ Male ☐

2) Age

Less than 30 ☐ 30 to 39 ☐ 40 to 49 ☐ 50 to 59 ☐ 60 and above ☐

3) Do you wear glasses when you read?

Yes ☐ No ☐

4) In general, how much time do you spend in your work area?

All the time (7-8 hours of day) ☐

Most of the time (4-6 hours of day) ☐

Very little (less than 4 hours a day) ☐

Others (please specify) ☐

5) Which of the following tasks are most common in your area activity?

Using PC ☐ Reading ☐ Writing ☐ Others (please specify) ☐

6) Do you prefer working in natural light, artificial light or combination of both?

Prefer natural ☐ Prefer artificial ☐ Prefer combination ☐

7) In which space are you currently located?

Office ☐ Reception Area ☐ Reading Room ☐ Others (please specify) ☐

8) In your current location, where is the light source?

**You can select more than one answer.*

Above-head dome ☐ Window ☐ Artificial lighting ☐

9) Describe your visual comfort in this room when only depending on natural lighting?

Bright 1 2 3 4 5 6 7 Dark

10) From your present location, do you experience any unpleasant gloomy (dark) area in the room?

Very much 1 2 3 4 5 6 7 Not at all

11) From your present location, do you experience any unpleasant bright (glare) area in the room?

Very much 1 2 3 4 5 6 7 Not at all

12) Is natural lighting alone enough to light this room?

Yes ☐ No ☐

13) How do you feel about the lighting in the current room?

Very pleased 1 2 3 4 5 6 7 Very unpleased

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QUESTIONNAIRE

Very comfortable 1 2 3 4 5 6 7 Very uncomfortable

14) Describe your visual comfort in this room when only depending on artificial lighting?

Bright 1 2 3 4 5 6 7 Dark

15) In general, how do you rate the light level (artificial and natural combined)?

a. At reading desk

Too much light 1 2 3 4 5 6 7 Too little light

b. In the room in general

Too much light 1 2 3 4 5 6 7 Too little light

c. In front of PC

Too much light 1 2 3 4 5 6 7 Too little light

16) Does the artificial light ever cause glare strong enough to bother you?

Yes ☐ No ☐

17) Does the lighting system match your visual needs?

Not at all 1 2 3 4 5 6 7 Absolutely

18) How do you classify the room's brightness during these hours (regardless of any weather condition)?

(i) Morning

Bright 1 2 3 4 5 6 7 Dark

(ii) Afternoon

Bright 1 2 3 4 5 6 7 Dark

(iii) Evening

Bright 1 2 3 4 5 6 7 Dark

19) Do you think that a desktop lamp would improve your working conditions?

Yes ☐ No ☐

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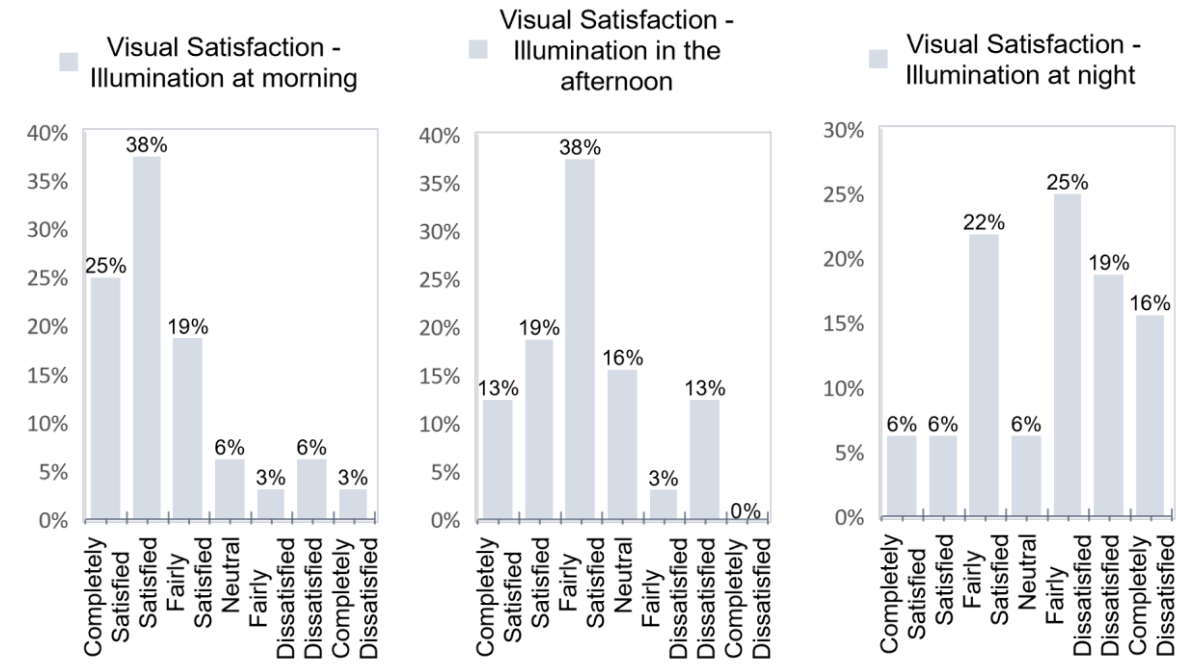
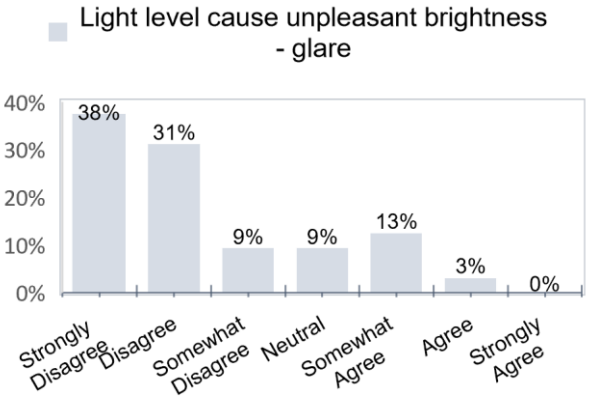
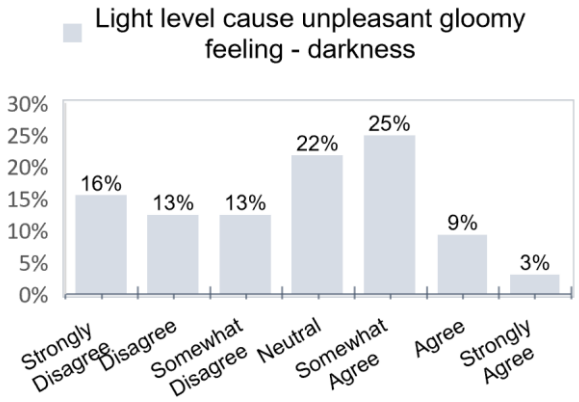
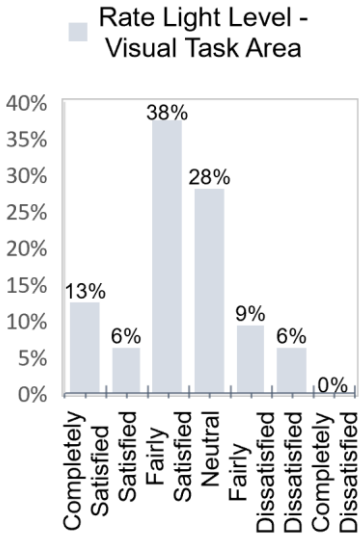
C. Survey Results Graphs

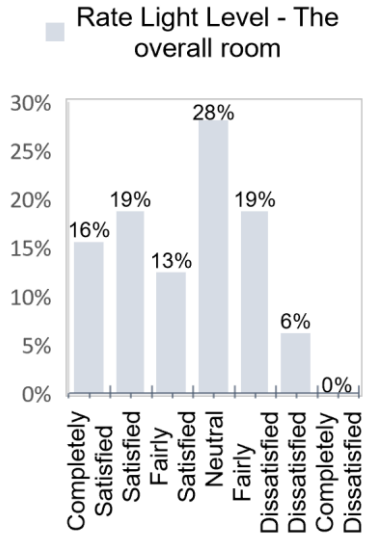
Table 71 – Generalized results for all participants and all zones

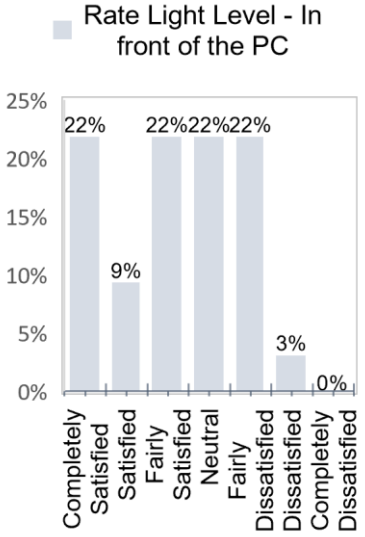












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