Modelling and analysis of daylighting relative to energy consumption of a heritage category A3 building under energy zone 4 in South Africa

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DECLARATION

I, Ochuko Kelvin Overen, declare that this research report is my own unaided work, except where acknowledged. The report is submitted for the degree of Masters in Urban Studies (in the field of Sustainable & Energy Efficient Cities – MUS (SEEC)) at the University of the Witwatersrand. The research report has not been submitted before for any degree, nor is it under examination in any other University.

Signature of candidate____________________________________ Date …02 September 2022

ABSTRACT

Restriction of participating buildings in the recently promulgated energy performance certificate (EPC) regulations to buildings completed after 1999 might have a negative impact on intended outcomes considering that a significant number of public-use buildings in the country were completed before 1999. Arising from this concern, this study evaluates daylighting interventions for a heritage instruction-cum-office building with the objective of reducing overall energy-use intensity (EUI), related operational energy cost and CO_2 emissions. A quantitative study approach based on experimental and simulation research tools was employed on Livingstone Hall (University of Fort Hare, Alice campus in Eastern Cape) as the case study building.

Through measurements and simulation, indoor daylighting levels were evaluated against the 300 lux threshold (recommended workplace illuminance levels in South Africa). The data indicate that on typical clear sky days in summer and winter, average daylight illuminance for 50% of the six sample spaces was below 300 lux, while for typical cloudy-sky days in both seasons, daylight illuminance for all the spaces was below 300 lux. This implies that, for cloudy-sky days in both seasons, daylight cannot fully replace electric lighting for office and academic tasks in the building.

Based on simulation results, for a typical summer clear-sky day, the average daylight illuminance in spaces 41, 43, 49, 11, 15 and 22 was up to 2 000 lux, while average daylighting in the same spaces on a typical winter clear-sky day was relatively lower. In addition, the annual "as-is" cumulative energy-use of the building was 49.02 MWh, and overall EUI was 31 $kWh/m^2/yr$. The annual operational energy cost of the building was R67 108.50, while receptacle equipment (devices such as computers and other appliances connected to sockets) energy cost was R32 702.14 and the energy cost of electric lighting was R20 091.86. Cumulatively, the annual CO_2 emission of the building was 25 440 kg (averaging 2 120 kg /month). Automated on/off and continuous dimming (smooth decrease of electric lighting capacity with ambient illuminance at a pre-set light level) daylight interventions were considered in the study. Continuous dimming intervention shows the best reduction in annual lighting energy-use by 64% and overall annual energy-use by 20%, while overall EUI reduced by 19%. The resultant overall energy cost saving was R12 420.73 while mitigated CO_2 emission was 4 839 kg per annum.

Keywords: *Daylighting, energy efficiency, energy-use intensity, heritage building, illuminance, visual comfort*

DEDICATION

To my late mother; Madam Patience Orubor Ogboriaphe

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CHAPTER 1

INTRODUCTION, CONTEXTUALISATION AND MOTIVATION OF THE STUDY

1.1 Background and Contextualisation of the Study

According to the International Energy Agency (IEA) and United Nations Environment Programme (UNEP) (2019), buildings account for approximately 40% of global final energy consumption and related greenhouse gas emissions. This is mainly due to energy-use in the operation and construction of residential, commercial, and other buildings in both public and private sectors. In view of the 7% building consumption increase between 2010 and 2018, IEA and UNEP (2019) emphasise that even though many countries have set building energy efficiency initiatives to achieve the UN SDGs (sustainable development goals) and the Paris Climate Change Agreement targets, building energy reduction was not on track to meet the set targets.

As highlighted in the World Energy Council (2020:87), various countries have established action priorities to achieve energy transition to meet global humanity energy challenges. Action priorities in this context are the economic, energy efficiency and renewable energy activities embarked on by global energy leaders to achieve energy transition (World Energy Council, 2020). In this regard, Germany set a target to reduce building energy consumption by 20% and 50% by 2020 and 2050, respectively. China has also adopted electricity price subsidies to encourage energy efficiency practices (World Energy Council, 2020:111). Switzerland has a similar approach that incentivises energy efficiency retrofit in buildings (*ibid.*:119). On the other hand, South Korea uses digital technology to reduce energy consumption in residential and commercial buildings through a comprehensive database and automated interventions coupled with artificial intelligence. (*ibid.*:45).

Similarly, as a signatory to the Paris Agreement, South Africa has formulated its building energy efficiency action priority. As of December 2020, it is mandatory by law for all new and existing public buildings completed since 1999 to display and submit energy performance certificate (EPC) (Department of Mineral Resources and Energy, 2020). The energy performance ratings of a building in the EPC programme are based on SANS1544 of the South African Bureau of Standards - SABS (2021) recommended annual maximum energy consumption of the various occupancy categories in the different energy zones. Hence, building energy performance varies with occupancy-type categories and climate zones. The occupancy-type categories include hospitals, hotels, offices, places of worship, instruction, entertainment and public assembly. Other criteria for EPC requirements are that the building should have a minimum net floor area of over 2 000 m^2, no major renovation within the past two years of operation and must have been completed after 1999 (Milford, 2015:6).

It is anticipated that the next step in the EPC process will be to set targets/standards in energy-use intensity (EUI) for existing public buildings (similar to what has been in force for new buildings since 2011), followed by enforcing compliance through energy efficiency interventions. In view of daylighting optimisation towards reducing energy for lighting in such buildings ((Li, Wu, Yuan and Zuo, 2021)), this study envisages that retrofitting of effective daylighting interventions will become significant in the subsequent stage of optimising energy performance, especially in the contribution towards the country's climate change mitigation commitments as well as towards energy security.

While the rapid innovations and diffusion of lighting technologies, from incandescent and magnetic ballast fluorescent fittings to light-emitting diode (LED) and electronic ballast fluorescent fittings, have reduced lighting energy consumption in buildings, daylight remains the only free, zero-energy and zero-carbon light source (Eskom, 2015, Kwong, 2020 and Mantzourani, Doulos, Kontadakis and Tsangrassoulis 2020). In addition to its energy savings potential, studies such as Chinazzo, Wienold and Andersen (2019), Öner, Kazanasmaz, Leccese, and Salvadori (2020) and Wirz-Justice, Skene and Münch (2020) clearly demonstrate that daylighting improves well-being, health, and productivity in the workplace. Whereas the energy and psychological benefits of daylighting have been systematically studied, design-optimisation for daylighting in buildings, and specifically in public buildings, remains a major challenge (Kwong, 2020). As a response towards addressing the challenge, Kwong (2020:1) further notes that the Malaysian Government enforces daylighting optimisation by making it mandatory through its building policy and regulations.

In terms of regulating and evaluating levels of indoor daylighting, qualitative and quantitative methods can be adopted (Michael, Gregoriou and Kalogirou, 2018). Qualitative methods focus on daylight's contribution to visual comfort or stress based on occupants' perception. In contrast, quantitative approaches deal with measurable daylight relative to the building design, interventions, ambient weather conditions and surrounding features of the site/area in which the building is located.

The quantitative approach is also used to derive potential savings in energy-use for lighting due to interventions aimed at optimisation of daylighting through design (*ibid.*). Over the years, the three commonly used measures for quantifying daylight levels in buildings are Daylight

Autonomy (DA), Daylight Factor (DF) and Useful Daylight Illuminance (UDI) (Bian and Ma, 2017 and Zhang and Lu, 2019). These measures are also applied in building information modelling (BIM) applications such as IES-VE, DiaLux, DesignBuilder and EnergyPlus to simulate performance in daylighting and related energy-use performance during the early design stage of a building or for energy efficiency retrofit for existing buildings (Bernett, Kral and Dogan, 2021; Elakkad and Ismaeel, 2021).

1.2 Theoretical Contextualisation

The key theoretical themes underlying the scope of the study are the concept of daylight, workplace light level requirements and daylight metrics, as well as lighting energy efficiency interventions for commercial/public buildings in South Africa and daylight-linked automated control systems for commercial buildings

1.2.1 Theoretical overview of daylight.

At the upper levels of the earth's atmosphere, the solar radiation spectrum consists of 9% ultraviolet, 50% infrared and 40% visible radiation (Hinrichs and Kleinbach, 2013). However, only approximately half of that radiation reaches the earth's surface due to reflection, absorption and scattering as it travels through the atmosphere (*ibid.*). Although reflection alters the overall flux density of solar radiation reaching the earth's surface, scattering affects visible radiation (Kreider, Curtiss and Rabl, 2009). The solar energy balance reaching the earth after atmospheric interference is presented in Figure 1.1.

At the earth's surface, solar radiation is sensed mainly as direct normal and diffused horizontal radiation. Radiation reaching the earth's surface without attenuation is referred to as direct normal radiation, while the fraction of solar radiation after atmospheric attenuation is known as diffuse radiation. A combination of diffuse and direct radiations is referred to as global horizontal radiation. Lastly, the reflected solar radiation from the earth's surface (land, water, vegetation cover, as well as buildings) is called albedo or reflected radiation (Overen, Meyer and Makaka, 2021b). Studies such as Kunwar, Cetin, Passe, Zhou, and Li (2020) and Kwong (2020) have demonstrated that diffuse and reflected radiations are conducive to daylighting. In contrast, Kunwar *et al.* (2020) highlight that direct solar radiation, it contributes to visual discomfort primarily due to glare, while also likely to contribute to excessive heat-gain inside the building once short-wave radiation is converted to long-wave radiation (hence the greenhouse effect), which we then sense as heat.

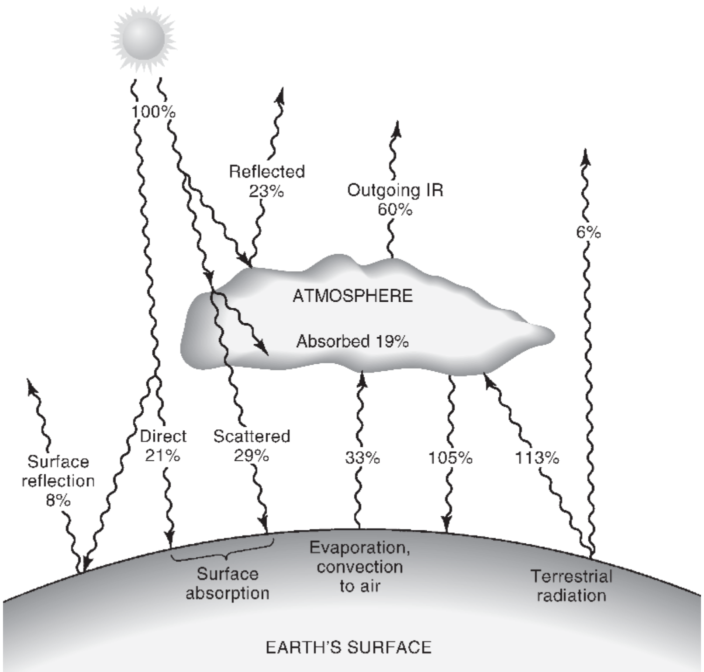


Figure 1.1: Solar earth-atmosphere energy balance system (Hinrichs and Kleinbach, 2013:156)

Wirz-Justice *et al.* (2020:2) define daylight as atmospherically attenuated indirect and direct electromagnetic solar radiation reaching the earth's surface. The authors (*ibid.*) further emphasise that daylight duration and availability depend on atmospheric conditions, season, and geographic latitude. Boodu (2021) also note that daylight availability in a building is influenced by the interaction between design (windows position/orientation, size and proximity of ambient obstructions), local climate and specific weather conditions., In a review of workplace lighting requirements, Choi, Loftness, and Aziz *(*2012:167) stress that light quality is crucial for visual comfort and workplace safety as well as productivity. Several countries have therefore established recommended light levels for various workplaces in order to ensure workers' safety, health, and enhanced productivity. For example, the Chartered Institution of Building Services Engineers of the United Kingdom recommends 300 lux for moderately easy visual tasks and 500 lux for tasks that require a high level of accuracy (Yu and Su, 2015 and Zhang *et al.,* 2019). Similarly, the Illuminating Engineering Society in the United States recommends 500 lux for paper-based tasks in contrast to 300 lux recommended for computer-based tasks (Choi *et al*., 2012 and Yu *et al*., 2015). Krüger and Dorigo (2008) indicate that the Brazilian Standard NBR 5413 recommend between 200 lux and 500 lux for teaching, lecturing, and learning activities. The South African Government has set a 300 lux benchmark for conference rooms and general office tasks (Department of Labour, 1993). These examples indicate that lighting-level requirements are task-specific and also vary from one country to another. Szokolay (2004:146) emphasises that an effective lighting requirement needs to consider the contrast, speed, and level of details of the visual task. Szokolay further argues that age should also be considered because human visual acuity tends to deteriorate with age.

1.2.2 Lighting control and daylighting for energy savings in commercial buildings

No matter how efficient a lamp is, inadequate control will result in excessive energy consumption (Eskom, 2015). Similarly, the integration of daylight in a building does not automatically contribute to energy savings. Daylight-linked lighting control is therefore often required to achieve the desired energy savings. Occupancy and daylight-linked sensors are the commonly used automated lighting control technologies (Roisin, Bodart, Deneyer and D'Herdt, 2008 and Yu *et al.*, 2015). Occupancy control operates in two distinctive detection modes, which are presence and absence. In presence-detection, the sensor automatically switches on electric lights once motion is sensed and off when the space is not in use/occupied. Electric lights would still need to be manually switched on, and the sensor then switches off the light when the occupant vacates the space without doing so (*ibid.*). Roisin *et al.* (2008: 522) assessed the lighting energy-savings potential in office spaces using daylight-linked, occupancy dimming and on/off lighting controls. Their study concluded that energy savings due to occupancy lighting control depend on occupation rate and control mechanism.

Furthermore, daylight-linked control relies on photosensors to control the operation of electric lights based on ambient daylight levels (Overen and Meyer, 2019). Yu *et al.* (2015) identify two common daylight-linked controls, which are dimming control and on/off control. Daylight-linked dimming control sensors use the available daylight level to vary the output of electric lights (*ibid.*). In this control, the photosensor is usually mounted on the ceiling and facing downward towards a specific space (working plane) indoors (Lim, Keumala and Ghafar, 2017).

Yu *et al.* (2015) further indicate that the electric light output in daylight-linked dimming control is proportional to energy consumption. Lighting energy savings would therefore be proportional to levels of daylight transmitted indoors through the windows. On the other hand, on/off daylight-linked control uses an outward-facing sensor to switch electric lights on or off based on pre-set illuminance (Lim *et al.*, 2017). In other words, when the indoor ambient daylight level is equal to or above the pre-set illuminance, the sensor switches off the electric lights and subsequently on when the indoor daylight level is below the set level (Yu *et al.*, 2015). Under this control, the total period the indoor daylight level is equal to or above the pre-set illuminance is used to determine the lighting energy savings (*ibid.*).

Based on the field measurement of an office building, Onaygil and Güler (2003:977) reported that daylight-linked lighting control saves approximately 30% of lighting energy consumption under Istanbul's (Turkey) climate conditions. The authors (*ibid.*:977) indicate that daylight-linked energy savings are seasonal, with savings increasing in the summer season by up to 10%. The sky condition is also a contributing factor to the performance of daylight-linked technology (*ibid.*). Findings by Alrubaih, Zain, Alghoul, Ibrahim, Shameri, and Elayeb (2013) corroborate Onaygil and Güler (2003) findings and further suggest that irrespective of the daylight-linked control strategy, daylighting has the potential for more than 50% lighting energy-savings. Shailesh and Raikar (2010:33) also argue that about 70% savings on electric lighting energy consumption could be achieved by combining occupancy and daylight-linked sensors in a building.

1.2.3 Lighting energy efficiency interventions for commercial buildings in South Africa

that the invested in nationwide South Africa's national power utility (Eskom) launched the national EEDSM in 2004 under the administration of the National Energy Regulator of South Africa (NERSA) (Etzinger, 2014:1). Etzinger (2014:3) further indicates that in response to the evolving energy landscape, the scope and focus of EEDSM were changed and renamed Integrated Demand Management (IDM) which was aimed at promoting energy efficiency practice in South Africa, specifically in the commercial, residential and industrial sectors through the use of rebates, standard product, standard offer, energy services company (ESCo) funding process, and performance contract funding models. Retrofit initiatives such as energy-efficient lighting, water heating, efficient motors, and heating, ventilation air condition (HVAC) systems were notable IDM projects in the commercial-building sector (Eskom, 2013).

IDM also entailed the replacement of inefficient lights such as incandescent and halogen lamps or fluorescent tubes with magnetic ballast with efficient lights such as LED, compact fluorescent lamp (CFL) or fluorescent electronic ballast. Motion sensor light controls (on/off) were also used in some projects. However, overall lighting energy interventions depended on the nature of the building owner/user organisation, type of task, targeted energy savings as well as the financial capability of the client or ESCo involved. The key principle of IDM initiatives target energy savings without compromising workplace safety and productivity at a time when supportive policies and regulations for existing buildings have not yet been promulgated (Etzinger, 2014).

1.3 Rationale

The prevailing carbon-intensity and electricity-supply crisis facing the South African economy places an enormous burden on the government in terms of its international climate-change mitigation commitments while also ensuring energy security for the country. Decoupling energy consumption and carbon intensity from economic growth through initiatives such as the newly launched EPC is a substantial step towards reducing strain on the national grid and the associated greenhouse gas (GHG) emissions. In line with the national building energy efficiency action priority, modelling and simulation of the energy performance of a heritage instruction-cum-office building would reveal the extent to which such buildings could also contribute to the national energy efficiency scheme while also improving on well-being and productivity of their users. Daylighting analysis of the building covered in the report also highlights the potential of adopting daylighting interventions to reduce EUI, operational costs and mitigation of GHG emissions for heritage buildings in the country without major modifications, which could undermine their heritage status.

1.4 Problem Statement

South Africa is currently undergoing its worst electricity-supply crisis, with persistent load shedding over the past three years. This is attributed to overstrained national grid due to the increasing energy demand and ageing coal-fired power plants with inadequate addition of new generation capacity. The Chief Executive Officer of Eskom (the national electricity utility) has indicated a high possibility that the ongoing electricity crisis will continue for another five years (Ash, 2021). Amid this crisis, the energy consumption of commercial buildings increased by 9% between 2015 and 2019 (Eskom, 2019). In 2019, Eskom also recorded its highest particulate matter and GHG emissions in 20 years (*ibid.*). The growing energy demand and ageing power plants also exacerbate the utility's non-compliance with the country's environmental standards and regulations, especially in relation to air-quality impacts of pollution from coal-power stations.

In addition to the electricity supply shortage and negative environmental impact, Eskom has persistently sought higher-than-inflation tariff increases in order to mitigate its deteriorating financial performance, thus indirectly passing the financial burden to electricity consumers, which in turn undermines economic growth. The national energy efficiency strategy for public buildings (which now includes EPC regulations) can therefore be viewed as a long term economic and environmentally friendly approach towards addressing the country's electricity challenges. However, reduced participation due to building age (exclusion of buildings completed prior to 1999) will negatively impact the efficacy of the policy, mainly because most of the country's stock of public-use buildings were completed before 1999, even when they are not necessarily heritage buildings (Milford, 2015:6).

1.5 Aim and Objectives

In view of the challenges outlined above and based on a case study of a heritage instruction-cum-office building, this study evaluates the extent to which daylight optimisation interventions can reduce overall EUI and operational costs while also contributing to the mitigation of environmental impacts such as GHG emissions. In order to achieve this aim, the study was guided by the following objectives:

- Determine status quo daylighting levels by installing photometric sensors and data loggers in the case study building
- Assess the outdoor luminance levels based on outdoor photometric and solar radiation sensors and data loggers
- Conduct a walk-through audit of the building envelope components (including critical dimensions for modelling), materials properties, floor area, count of electric lights and appliances (including their power ratings), as well as the schedule of use of the building. These were the critical simulation inputs used to derive the EUI
- Derive overall "as-is" EUI performance of the building as well as daylighting optimised performance based on a range of feasible interventions and resultant financial, and environmental benefits

1.6 Research Question and Related Sub-questions

The overall research question which guided the study was articulated as follows:

What is the potential contribution of daylighting optimisation towards EUI-reduction in a heritage place-of-instruction building in South Africa, and what are the possible daylighting interventions towards reducing EUI and enhanced financial and environmental benefits of such buildings?

The sub-questions towards addressing the main research question were articulated around the case-study building, which falls under energy zone 4 as per the 2nd edition of SANS10400-XA. The sub-questions were articulated as follows:

- What is the status quo ("as-is") EUI for the selected case study building?

- What are the potential daylighting optimisation interventions of the case study building while also adhering to its heritage status?
- What would be the contribution of daylighting optimisation interventions towards the reduction of EUI of the building?
- What would be the feasibility of retrofitting such daylighting optimisation interventions?

1.7 Working Hypothesis

Given that climate zone 4 under SANS10400-XA is characterised by 1 765.6 kWh/m^2 solar radiation per annum (SOLARGIS, 2017), an average of 13 hours of daylight in summer and 10 hours in winter season (Overen, Meyer and Makaka, 2021a), daylighting indoors can enhance EUI-reduction by up to 50% of lighting energy-use as observed in Alrubaih, Zain, Alghoul, Ibrahim, Shameri and Elayeb, (2013), and thus contribute to global climate change mitigation. Typical heritage buildings are most likely to be deficient in their design towards utilising daylighting for EUI-reduction. Heritage buildings in South Africa are also not commonly considered in energy efficiency optimisation through retrofitting of responsive interventions as they are normally deemed to be disruptive to the heritage value of such buildings (Milford, 2015). However, considering the available solar radiation in energy zone 4 and the use of non-invasive lighting interventions such as daylight-linked and occupancy control, the heritage category A3 building could save up to 50% of lighting energy usage as well as contribute to operational-cost reduction and mitigation of GHG-emissions.

1.8 Expected Findings

As-is lighting energy and potential daylighting energy saving of selected offices in the building were anticipated at the end of the research. This involves daylight illuminance of selected offices at desk level on both floors and a simulated whole-building daylight distribution, building electrical energy savings due to daylight, resultant cost savings and environmental mitigation. Based on the findings, lighting energy cost and environmental impact of the building were deduced. In addition, the whole-building EUI, operational cost, and environmental impact were simulated. The simulation also covers non-invasive lighting interventions for optimised EUI.

1.9 Definition of Key Terms

- Area of interest (AOI) is the region in a space, usually 0.5 m away from the perimeter walls and windows, used to evaluate daylight level or quality.

- Automated on/off daylight-linked operation uses a photosensor to automatically switch on and off of electric lights based on pre-set indoor ambient light levels (Atif and Galasiu, 2003 and Lim *et al*., 2017).
- Conditioned spaces are areas or rooms in a building that are mechanically or electrically thermally conditioned for thermal comfort.
- Continuous dimming daylight-linked operation uses a photosensor to gradually decrease the capacity of electric lighting with indoor ambient illuminance to a pre-set light level (Atif and Galasiu, 2003 and Yu *et al*., 2015).
- Daylight Autonomy is the percentage of annual daytime hours that a work plane is above or within the recommended light level (Bian *et al*., 2017).
- Daylight factor is expressed as the ratio of indoor daylight level to unobstructed outdoor ambient horizontal daylight illuminance under the International Commission for Illuminance (CIE) Overcast Sky Standard (Tregenza and Mardaljevic, 2018).
- Energy use intensity (EUI) (kWh/m^2) is the annual energy consumption of a building per net total floor area where the floor area only takes into consideration the active area of a building, thus excluding spaces such as the garage, bathrooms and outdoor areas.
- Luminance (cd/m^2) is the amount of light passing through an opening, emitting, or reflecting off an object.
- Illuminance (lux) or light level is the amount of daylight falling onto a specific surface area.
- Side-lighting is a daylighting design strategy that harvests natural lights through vertical windows, for example, windows on the walls (Alrubaih *et al*., 2013 and Bradshaw, 2006).
- Top-lighting is a daylighting design strategy that harvests natural lights through vertical windows, for example, skylights (Alrubaih *et al*., 2013 and Bradshaw, 2006).
- Useful daylight illuminance is the annual percentage of daytime hours that a work plane illuminance is within a specified range of light level (Zhang *et al*., 2019).
- Work plane is the height at which daylight illuminance in a given space is evaluated, and it is usually at 0.77 m to 0.85 m above floor level, equivalent to the height of a typical office desk.

1.10 Delineation

In this study, daylight observation of the building was conducted using experimental and simulation approaches. In the experimental approach, photometric sensors were used to monitor the illuminance on the desk of selected offices in the building. The measurement captured the operating daylight conditions of the selected offices, i.e., the effect of the blinds on the available daylight, electric and ambient lights were involved. Therefore, the daylight illuminance of the spaces was obtained by deducting the average illuminance during the sun's absence from the average illuminance during the sun's presence. The sun absence and presence were observed from the measured global horizontal irradiance (GHI) based on the assumptions that periods with GHI greater than 0 W/m^2 imply the sun presence while the sun absence is the periods with GHI below 0 W/m^2. GHI was also used to determine clear and cloudy sky days for daily daylight evaluation of the building. Further, spaces with daylight illuminance greater than 300 lux were considered sufficient to utilise daylight for energy savings.

The simulation approach evaluates the whole-building daylighting and energy performance, focusing on conditioned spaces. However, daylighting simulation of the building was based on Bisho town satellite-based weather data and the original building design, which did not include the windows' cover and electric lights' illuminance. Regarding the building energy performance, lighting and appliance energy forms the whole-building consumption. Their respective operating periods, as used to simulate the energy consumption, were obtained from the academic schedules in the building. In addition, the research only covers fixed fenestration, i.e., allowable fenestration changes for heritage buildings towards improving daylight indoors were not considered in the research.

1.11 Structure of the Research Report

This section provides the structure of the research report in terms of chapters and content, as summarised in Table1-1.

Table 1-1: Structure of the research report.

Chapter	Heading (title)	Description
1	Introduction	In this chapter, the research background, problem statement, aim and objectives are outlined and discussed
2	Literature review (building lighting energy efficiency and daylight design)	Sample studies on two key themes that the research is based on are presented and appraised in this chapter. The chapter starts with an overview of lighting energy efficiency interventions in public (office) buildings. Thereafter, studies on building design interventions for optimum daylight performance are outlined and appraised
3	Research method (daylight level and energy measurement, estimation, and simulation)	The various methods and data tools used in measuring the "as-is" daylight level in the offices are presented and discussed in this chapter. Assumptions and formulae used in estimating the lighting energy consumption,

		operational cost, and environmental impact are presented and reviewed. The chapter also covers “as-is” daylight levels and energy performance modelling procedures for the entire building
4	Results and discussion (“as-is” daylighting and potential energy savings of simulated interventions)	This chapter presents data and analyses for the “as-is” daylighting levels of selected spaces in the building and the resultant energy consumption and operational cost.
5	Results and discussion (Simulation and Optimisation of the Building Daylight and Lighting Energy Performances)	The chapter presents the simulated whole-building daylight level, EUI, operational cost, and related GHG emissions. In addition, data and analyses on the various lighting energy interventions adopted to optimise building energy performance are presented and discussed in this chapter. The discussion covers the optimised EUI, operational cost and environmental impact of the building.
6	Overall findings, conclusions and recommendations	The chapter presents the key findings of the study in relation to the objectives and overall research question of the study. The chapter also presents the recommendations for future studies on daylighting in heritage category A3 buildings in South Africa.

CHAPTER 2

LITERATURE REVIEW – DAYLIGHT-LINKED CONTROL FOR LIGHTING ENERGY EFFICIENCY

2.1 Introduction

Globally, building energy consumption has been a central demand-side focus towards achieving net-zero carbon emission and based on design interventions in lighting, heating, ventilation and air conditioning (HVAC) and appliances. The International Energy Agency (IEA) (2021:146) anticipates that electrical appliances and lighting will become much more efficient in the next three decades leading to 2050 due to energy-use policies as well as ongoing escalations in technological innovations. As an example, the report envisages that the proportion of LED lamps in total light fixture sales will reach 100% by 2025 (*ibid.*). In advancing the global net-zero energy building target, Hong Kong Green Building Council launched a green building best practice guidebook (Hong Kong Green Building Council Limited, 2021), which recommends 32 strategies for smart green buildings under six key themes: building design and operation, health and well-being, energy performance, material and waste management, water performance, and mobility and transportation. The health and well-being theme deals with the use of smart technologies to ensure and maintain building environmental quality pertaining to occupants' health and well-being, smart artificial lighting, advanced solar technologies for natural lighting and smart light poles. The guidebook also emphasised that the use of advanced solar technologies could save 15 to 40% energy by reducing energy for artificial light while also enhancing occupant comfort and well-being (*ibid.*:36). The Green Building Council South Africa is equivalent to Hong Kong Green Building Council that promotes energy and environmentally sustainable building design through certification.

Krarti, Erickson and Hillman (2005) suggest that the lack of evaluation methods for daylighting suitability and potential energy savings has been the main reason for the ongoing reluctance towards optimisation of daylighting in buildings. Although numerous studies such as Lee, Lam and Lee (2018) emphasise the substantial lighting energy-savings through energy efficient light retrofitting and automation control systems, such studies also stress that the lack of capital and technological awareness are the main factors hindering building owners from considering and implementing retrofitting for daylighting optimisation interventions.

Guided by this insight, this Chapter reviews studies on the various concepts of lighting energy efficiency in buildings and basic daylighting design. In particular, the studies reviewed cover lighting energy efficiency strategies and the application of the two major lighting automation control systems, which are occupancy-based and daylight-linked. Studies in lighting energy savings estimation are subsequently reviewed, followed by a discussion on strategies of daylighting design and a conclusion on the key insights for the study. Some of the key studies appraised are Lee *et al.* (2018), Booysen, Samuels and Grobbelaar (2021), de Bakker, Aarts, Kort and Rosemann (2018), Lim, Keumala and Ghafar (2017), Chi, Moreno and Navarro (2018), Yu *et al*. (2015), Szokolay (2008), Boodu (2021), and Bradshaw (2006).

2.2 Theoretical overview of Building Orientation in the Northern and Southern Hemispheres

After atmospheric attenuation of solar radiation as discussed in Section 1.2.1, the radiation intensity reaching a given location on the earth's surface is determined by the latitude, season, time of day, and degree of cloud cover (Hinrichs and Kleinbach, 2013). According to Hinrichs and Kleinbach (2013), latitude and season are due to the earth's elliptical orbit around the sun as shown in Figure 2.1.

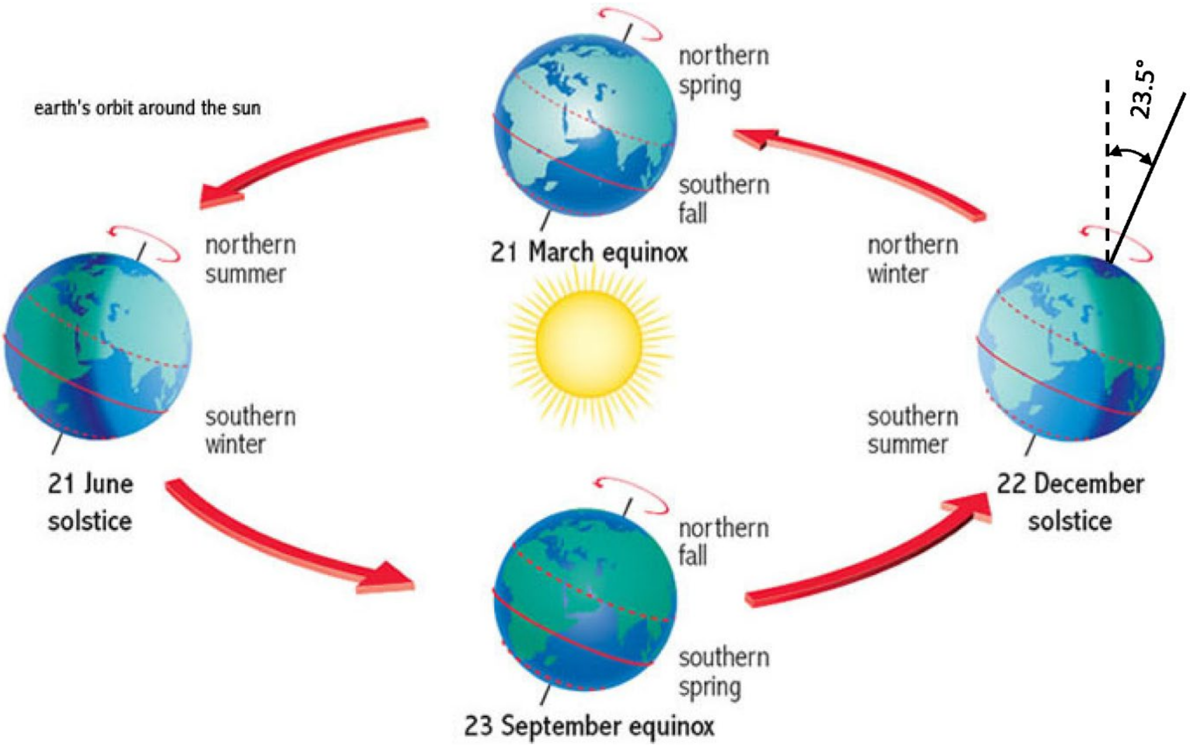


Figure 2.1: Revolution of the earth around the sun illustrating the Northern and Southern Seasons; adapted from (Hinrichs and Kleinbach, 2013:157).

As shown in Figure 2.1, the earth's spinning axis is tilted about its plane of motion at an angle of 23.5°. As a result, the south pole is tilted toward the sun during the southern hemisphere's summer and away from the sun during winter (Hinrichs and Kleinbach, 2013). Hence, locations in the southern hemisphere are exposed to higher solar intensity and sunlight hours in the summer season with a peak on 22 December which is the southern summer solstice. The reverse scenario occurs in the northern hemisphere, where the north pole is closer to the sun during the summer season, and peak solar intensity and sunlight hours are experienced on 22 June, the northern summer solstice (*ibid.*). In the winter season in both hemispheres, solar radiation is subjected to higher atmospheric absorption and scattering and thus spreads over a large surface. Consequently, low solar intensity and sunlight hours are experienced at the earth's surface during the winter season. Sun paths in the major seasons in both hemispheres are shown in Figure 2.2.

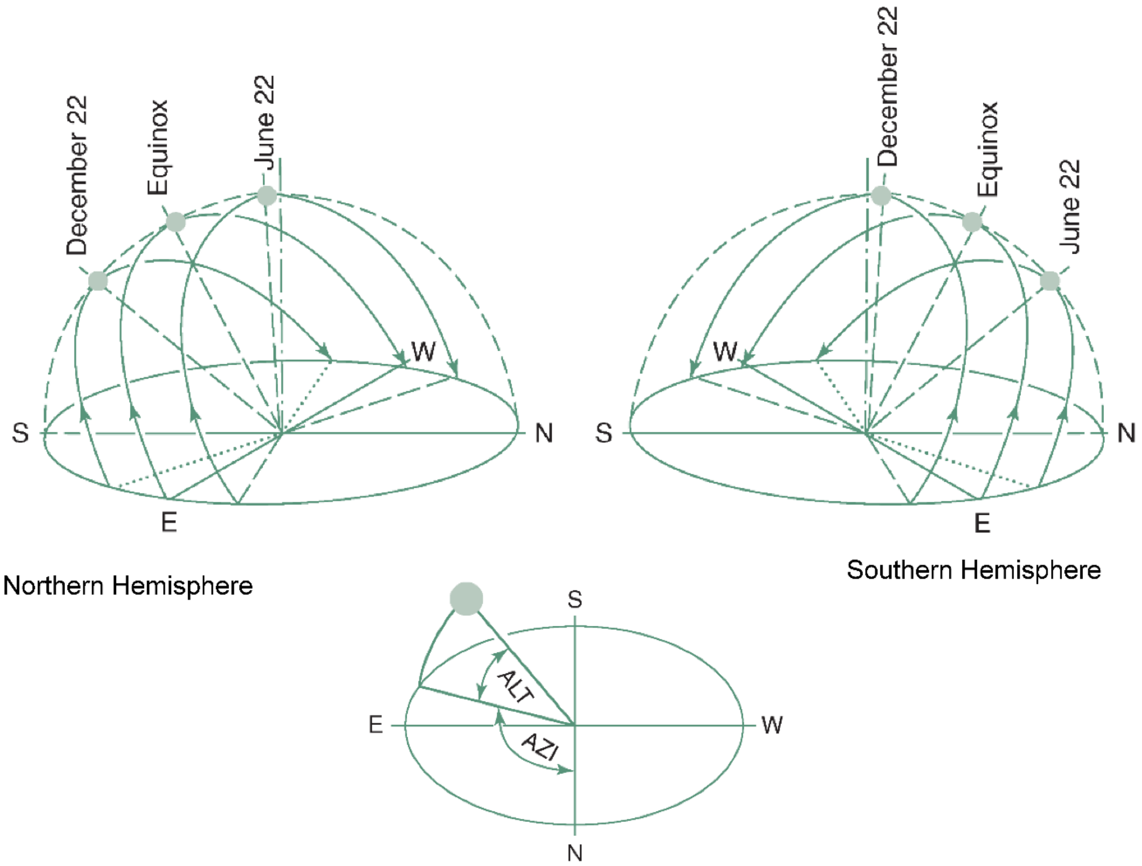


Figure 2.2: Seasonal sun path at the northern and southern hemispheres; adapted (Szokolay, 2008:164)

The sun angle above the horizon is referred to as altitude, while azimuth is the sun angle along the horizontal plane from 0 to 360 (Szokolay, 2008:164). The sun's altitude and azimuth are the most crucial parameters used in building design for effective solar access relative to the hemisphere, local climate conditions and building purposes. In this regard, changes in solar altitude influence seasonal solar penetration, while changes in azimuth angle influence the hourly solar penetration. In building design, both parameters are used to assess solar access and need for solar shading in relation to space heating and daylighting (Overen, Meyer and Makaka, 2021).

2.3 Daylighting Design

Natural light or outdoor light consists of sunlight, which is un-attenuated solar radiation from the sun, while daylight mainly consists of indirect solar radiation diffused within/through the atmosphere. Sunlight or daylight availability outdoors is therefore a factor of sky conditions which could range from clear, overcast and intermediate skies (Szokolay, 2008:149). According to Al-Obaidi, Ismail and Abdul Rahman (2015:9), the illuminance of clear sky outdoor daylight is between 10 000 lux to 22 000 lux, while during overcast sky, daylight illuminance ranges from 5 000 lux to 54 000 lux. On a clear sky day, direct sunlight can fall between 50 000 lux to 100 000 lux (Al-Obaidi *et al.*, 2015:9). However, Szokolay (2008:151) stresses that penetrating sunlight (direct radiation) through fenestration may be desirable or undesirable depending on the task indoors, mainly because such radiation entails high levels of thermal energy (infrared radiation) that may be desirable in the heating season (winter) or may result in thermal discomfort in the cooling season (summer) (Chi *et al.*, 2018 and Szokolay, 2008). Fenestration design is therefore a factor of building lighting requirements, but increased reliance on daylighting to achieve energy efficiency is likely to result in larger windows which may pose visual discomfort due to glare and thermal discomfort as well (Szokolay, 2008).

In addition to weather conditions, obstacles such as nearby buildings constitute another factor that influences access to daylighting indoors. Inappropriate urban planning may result in overshading from surrounding buildings (Boodu, 2021). According to Szokolay (2008:152), the "*right to sunlight*" was launched in the 19th century but only became a common practice in 1973 after the global energy crisis. This right created the foundation for many building codes that provide design requirements for daylighting and procedures for site inspection for potential daylight blockage before construction (Szokolay, 2004). Some of the approaches used for daylighting site assessment in relation to obstacles are presented in Figures 2.3 (a) to (d).

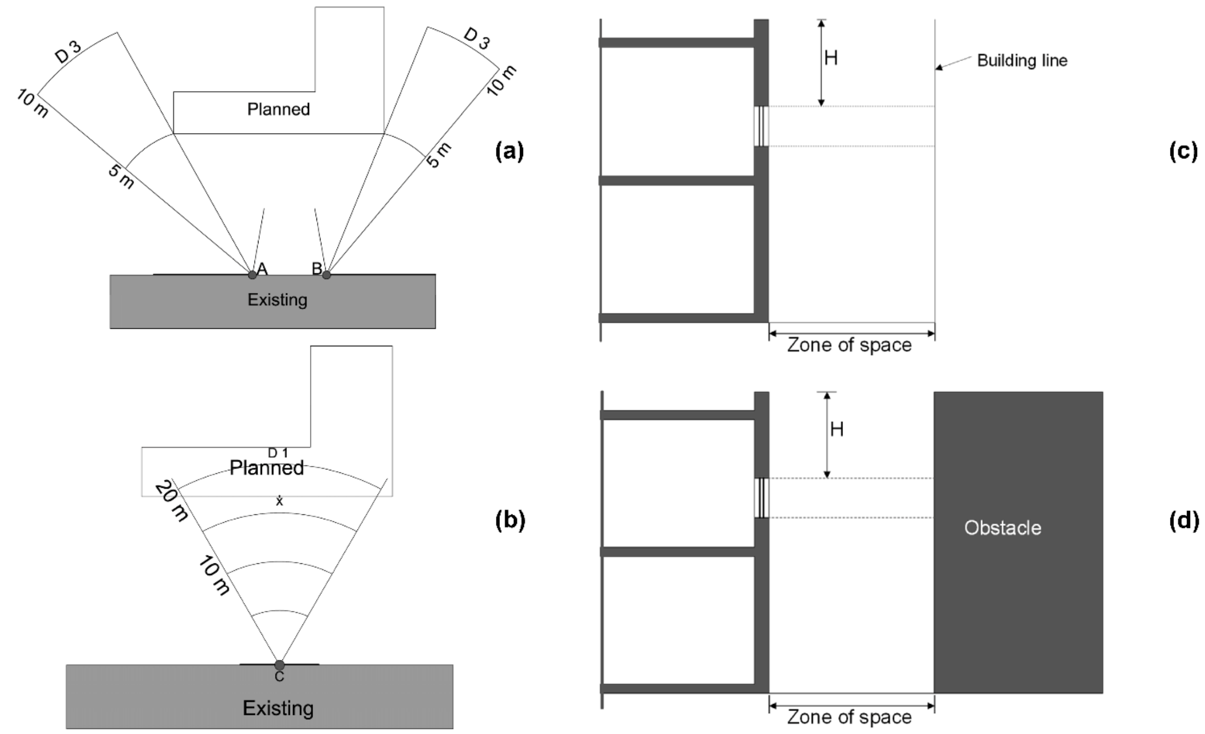


Figure 2.3: Site assessment approach for daylighting; (a and b) permissible height indicator (Szokolay, 2008:164) and (c and d) zone of space of natural light inspection (Boodu, 2021:36)

In Figure 2.3 (a) and (b), Szokolay (2008) indicates that the existing building or block from both ends to points A and B, respectively, receives adequate daylight from both sides of the planned building. Point C, which is halfway between points A and B, is the most crucial (Szokolay, 2008). Szokolay (2008:164) indicate that the permissive indicator D shows a permissible height of 13 m between the sill level of the ground floor at point C and X. From Figure 1 (c) and (d), Boodu (2021:35) alludes that according to SANS 10400-0: 4.2.1.2.6 and 4.2.1.2.7, the recommended length of zones of space of natural light for habitable rooms in dwelling houses, residential and commercial buildings is 1/3H where H represent the obstacle (building) height above the level of the opening head concerned. As defined by the author (*ibid.*:32), a zone of space is a volume of space around an opening in an external wall of a building.

As highlighted above, blockage of ambient sunrays by obstacles such as trees and adjacent buildings influences access to daylight in a building. However, as indicated in the appraised studies, building codes and regulations have been established to mitigate such daylight blockage. The appraised studies, therefore, serve as theoretical principles for evaluating the poor-lit sections of the case study building due to surrounding trees and adjacent buildings.

2.3.1 Design Strategies for Daylight Optimisation

As shown in Figure 2.4, the fundamental daylight design strategies are side-lighting and top-lighting (Alrubaih *et al.*, 2013 and Bradshaw, 2006). Bradshaw (2006:279) further highlights that fenestration for daylighting (primarily windows) can also serve other purposes but should be distinguished from openings for ventilation, passive solar heating and views.

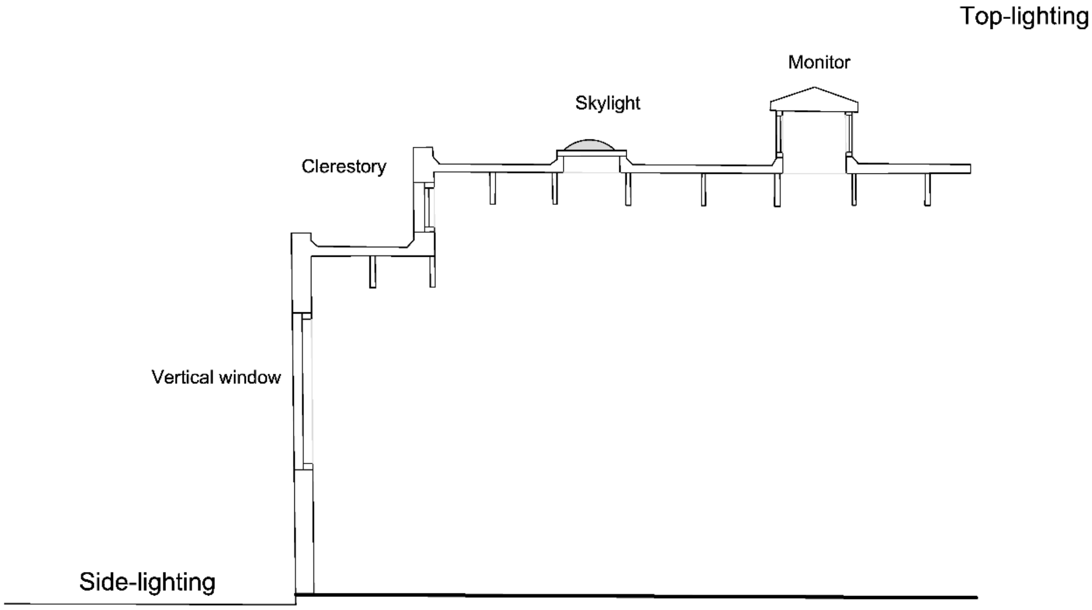


Figure 2.4: Type of fenestration for daylighting design (Bradshaw, 2006:280)

Alrubaih *et al.* (2013) emphasise that a side-lighting design or vertical window admits daylight at the wall of a building, while a top-lighting or roof window admits daylight at the upper part above the ceiling. Bradshaw (2006) argues that top-lighting or roof windows are more effective for daylighting than side-lighting since light from the sky is of greater quality than that of reflected landscape, and it is less diminished by surrounding obstacles. Alrubaih *et al.* (2013) share the same view, and further indicate that side-lighting is directional and diminish as the distance from the window or opening increases. Side-lighting is also associated with glares as the openings fall within occupants' field of view. In addition, top-lighting also allows designers to determine the geometry and orientation of daylight openings based on occupants' desire without the hindrance of the wall orientation.

In terms of thermal impact, Bradshaw (2006) discourages top-lighting in climates with high cooling load and also stresses that it is not a suitable solar heat collector for passive heating. Instead, the author (*ibid.*) recommends weather-tight, north-facing clerestory windows in the Southern hemisphere (south-facing in the northern hemisphere) for optimum solar heat gain in the heating season. Such design should also be accompanied by appropriate horizontal sunshading to avoid overheating in the cooling season. Where heating is not required, south-facing clerestory windows in the southern hemisphere are appropriate for more uniformly distributed daylighting (*ibid.*).

Bradshaw (2006) further highlights that the traditional use of windows (side-lighting) is not the only approach for effective daylighting. The study recommends that dedicated windows should be created at the building design stage in order to ensure that other purposes of the window, such as natural cooling and views, are not interfered with.

However, many heritage buildings, such as the case study building in this study, do not have dedicated windows for daylighting. They are confined to the use of side-lighting vertical windows, which also serve as openings for ventilation and views. Another crucial design strategy covered in the appraised studies is the use of geographical orientation of windows to selectively admit direct and diffuse components of solar radiation. For example, north-facing windows in the southern hemisphere will result in a significant amount of solar heat gain and possible glare in the winter season due to direct solar radiation. In contrast, south-facing windows in the southern hemisphere can be used to admit diffuse solar radiation with minimal solar heat gain and are therefore conducive to daylighting optimisation. As shown in Figure 2.2, north-facing facades in the southern hemisphere will receive varying levels of solar radiation between winter and summer seasons while south-facing facades will be in the shade throughout the year. In Figure 2.5, direct solar radiation in summer is prevented by the overhanging roof thus reducing solar heat gain and creating a mild daylight-lit space indoors.

On the other hand, low-angle sun rays in winter penetrate the window into the building, creating solar heating. The sun rays can also result in glare and visual discomfort depending on occupant's position relative to the sun rays and task of the occupant. Sunscreens and other window covers are usually used to mitigate visual discomfort due to direct or excessive solar radiation. Modern buildings adopt photo-automated sensors that operate such screens based on outdoor daylight illuminance. However, this drawback is not experienced in the south-facing sections of the building that are in the shade all year round. Spatial layout based on lighting requirements of tasks is another approach to effectively utilise high daylight illuminance on north-facing zones of a building.

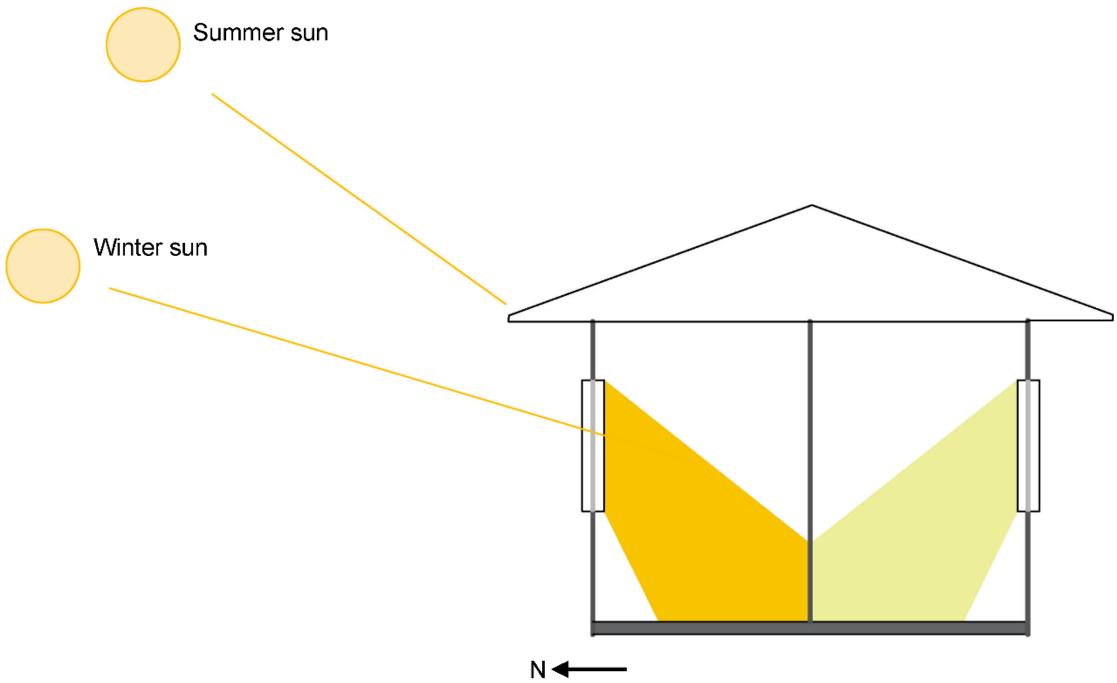


Figure 2.5: Summer and winter seasons' solar penetration in north oriented building in the southern hemisphere

The principles distilled from the appraised studies on daylighting design strategies served as crucial guides in analysing the ability of the case study building to admit effective daylight relative to its design. The studies also served as a theoretical evaluation of sections of the building with excess or poor light levels due to orientation of windows. In general, the studies provided a background understanding of daylight distribution relative to the opening type and geographical orientation of the building. This was then applied towards analysing the experimental (measured) and simulated data outputs.

2.4 Lighting Energy Efficiency Strategies

The replacement of energy inefficient lights such as incandescent and halogen lamps with efficient compact fluorescent lamps (CFL) and light-emitting diode (LED) is the most common lighting energy efficiency intervention for existing buildings. Krarti *et al.* (2005:747) allude that using CFL, occupancy-based light control sensors and designs that strategically minimise the required number of light fixtures can reduce operational energy and cost for new and existing buildings. Lee *et al.* (2018) share similar views with Krarti *et al.* (2005) but go further to argue that there is a high potential of performance risk in energy performance contracting projects for energy service companies (ESCos) in relation to lighting retrofit. The authors (*ibid.*) argue that the performance of energy efficient lighting retrofit is mainly influenced by factors that go beyond the ESCos control. The factors include lighting usage pattern, quantity and quality and frequency of maintenance. The study therefore explores a probabilistic approach to evaluate the performance risks of lighting retrofit interventions such as inefficient lights replacement, daylight-linked, and occupancy-based light control systems. In the study, EnergyPlus and Monte Carlo simulation techniques were adopted, while hypothetical T8 fluorescent tubes were replaced with T5 fluorescent tubes. One of the key study findings was that the potential annual lighting energy saving of a hypothetical 40 storey office building in Hong Kong would be between 1 267 and 1 927 MWh. Based on the wide range of energy savings, the study concludes that lighting retrofit poses performance and investment risk for ESCos engaged in performance contracting.

In contrast, Booysen, Samuels and Grobbelaar (2021) argue that lighting retrofit is one of the key approaches for schools in South Africa to navigate the electricity crisis associated with increasing tariff charges in the country. According to the study, in view of the diminishing costs of LED lamps, replacing fluorescent fixtures with LED lamps will save utility costs that can be allocated for much-needed academic services and also, benefit the struggling national utility and for mitigating environmental concerns such as GHG emissions. The study was based on energy savings, life-cycle cost, and CO_2 emission mitigation by replacing 1 170 58W – 60W T8 fluorescent fixtures with 19W – 32W LED lamps in sixteen schools in the Western Cape province of South Africa where the study was conducted. The energy savings per school day were estimated at 80 to 190 kWh with 80 to 180 kg CO_2 emission reduction, while the life-cycle cost savings vary from R298 180.00 to R766 570.00 based on the quality of lamps and tariff structures (*ibid*.:9).

In both studies, the replacement of inefficient lamps as a lighting energy efficiency strategy has been adequately demonstrated. However, Lee *et al.* (2018) argue that the associated performance risk for ESCos may serve as a hindrance for performance contracting based on light retrofitting. The study further indicates that agreed estimated energy savings can avert this challenge prior to project implementation. The use of energy efficient lighting can be used to reduce high utility costs and lessen pressure on the national grid and the environment in countries such as South Africa, which also has a carbon-intensive energy generation system (Booysen *et al.*, 2021). In terms of complementary or additional interventions, Doulos, Tsangrassoulis and Topalis (2008) emphasise that automated light control interventions such as occupancy-based, timer, and daylight-linked controls can improve lighting energy performance.

The studies covered in this section are relevant to this research as they reaffirm one of the simplest approaches to achieving lighting energy efficiency. Some of the interventions, such as replacing inefficient lamps with efficient ones, offer lighting energy savings intervention options evaluated in this study. CO_2 emission-reduction assessment and life-cycle cost savings calculation by Booysen *et al.* (2021) provides literature background information for the environmental and energy cost evaluation undertaken in this study.

2.4.1 Occupancy-based light control

According to Roisin, Bodart, Deneyer and D’Herdt (2008), lighting energy savings of occupancy sensors depend on the occupancy rate. In other words, light energy savings increase with a decrease in occupational rate. However, the study emphasises that the relationship between occupation rate and energy saving is not linear due to the sensor response time delay. The study compared the potential of lighting energy savings in office rooms using occupancy and daylight-linked control systems, and one of the key findings was that lighting energy saving is generally higher when occupancy control is supported with daylight-linked control as well. For such an intervention, savings can vary from 45 to 60%, depending on building orientation and occupancy rate. In addition, lighting energy savings are higher when on/off occupancy-based control sensors are used compared to dimming sensors.

In contrast to Roisin *et al.* (2008), De Bakker, Aarts, Kort and Rosemann (2018) argue that switching off lights in shared and single offices using an occupancy-based control device results in non-uniform illuminance distribution and an uncomfortable environment. Their findings show that using highly granular occupancy-based dimming sensors to control lights automatically reduces lighting energy in shared office space without impairing visual comfort. The study also investigated the feasibility of using granular occupancy-based light control on task, surrounding and background areas at various dimming levels. This was based on an open-plan office staged in a darkened laboratory room of 5.10 x 5.55 m with male and female participants between the age of 18 to 65 (de Bakker *et al.*, 2018).

The findings show high energy saving potential for all combinations of dimming levels, but the minimum dimming level in the background offers the most energy savings and visual comfort (*ibid.*). The study discloses that the obtained energy savings are influenced by the research method, such as the office size, layout and an assumption that absence from the office was only during lunch hours. Based on the findings of Chang and Hong (2013:29), the absence assumption is not realistic, mainly because absence from the office during the day varies from 10 to 29 minutes. Chang and Hong (2013:29) also discovered that the daily number of occupant absences and absence-duration significantly impacts lighting energy consumption and therefore contributes significantly to discrepancies between measured and simulated lighting energy saving.

Chang and Hong (2013) corroborate the findings of Saha, Florita, Henze and Sarkar (2019) that occupancy-based control is a crucial element of smart buildings where it adjusts settings according to occupant preferences as a fundamental human-machine interface due to a high proportion of time spent indoors. Saha *et al*. (2019) further outline three major algorithms for estimating building occupancy. The first one is detection which determines whether an occupant is present inside a particular space in a building or not. Secondly, the counting algorithm focuses on the number of people present in a given area or space in the building at a specific time. Lastly, the tracking algorithms are related to occupants' movement trajectory of a particular occupant inside the building (Saha *et al.*, 2019). It is worth noting that these algorithms equally apply to other energy-use systems of a building, such as HVAC systems.

In the above studies, contradictory views on the most effective application of occupancy-based lighting were expressed. Based on the views of Roisin *et al*. (2008) and De Bakker *et al.* (2018), automated on/off occupancy-based light control is most effective for single-offices while dimming occupancy-based is suitable for shared-offices. The effectiveness of both techniques in this context is related to occupants' perception and visual comfort, which also influence the energy saving potential. Another crucial aspect of occupancy-based light control is the occupant sensing algorithm. As defined by Saha *et al.* (2019), the sensing algorithm can also determine the suitable location of the occupancy-based light control. For example, detection sensing automatic on/off occupancy-based light control will be more effective in a single office. Similarly, tracking sensing dimming occupancy-based light control will result in more effective light control in a large shared-office space.

Given that occupancy-based light control is one of the commonly lighting energy efficiency interventions, the studies appraised provide the fundamental understanding and principles of applying occupancy-based lighting interventions in a building. The shortfalls of automatic on/off and dimming occupancy-based light control were distilled in order to serve as a guide in selecting lighting energy efficiency interventions in this study.

2.4.2 Daylight-linked control

In recent years, daylighting has proven to be an effective and useful strategy in modern architecture to achieve energy efficiency, visual comfort and user-friendly buildings (Alrubaih, Zain, Alghoul, Ibrahim, Shameri and Elayeb, 2013). Alrubaih *et al.* (2013) also note that daylight is the best light source for good colour rendering as it is closer to the human visual response. The study also emphasises that daylight in a building alone does not result in energy savings (*ibid.*:494). Integration of daylight-linked control with electric lighting is required to achieve energy efficiency through optimisation of daylighting (Alrubaih *et al.*, 2013). Based on this concept, Lim, Keumala and Ghafar (2017) explored the energy saving potential and user-behaviour of daylight-assisted task lights in a green design office building and overhead electric lights in a conventional design office in Malaysia. Their study argues that energy security and environmental sustainability can be achieved using task lights in office space. A quantitative approach that measures the ambient daylight level and indoor electric light level, as well as a qualitative method focusing on occupants' perceptions, were adopted in the research. The study quantifies lighting energy consumption using lighting power density (LPD), which was defined as the total wattage of lights installed per unit floor area. The study finds that task lights alone reduce the LPD by 0.60 W/m^2 while integrating daylight-linked control results in 3.04 W/m^2 reduction. Based on this finding, the study recommends that, for optimum energy savings, task lights could be combined with daylight-linked control systems. In addition, the study indicates that occupants expressed satisfaction with using task lights for paperwork and colour rendering but not for computer-related tasks.

The studies appraised in this section demonstrate the significance of daylighting towards energy efficiency. However, inappropriate integration of daylighting in a building can negatively impact building energy performance. Chi, Moreno and Navarro (2018) stress that in addition to visible radiation, sunlight consists of infrared and ultraviolet radiation that may result in overheating and glare when users are exposed to excessive sunlight. The study argues that the allowable amount of daylight within a space should be balanced to achieve adequate energy savings. Given that there are no benchmarks for daylight availability area, on-site energy used for artificial light supply, heating and cooling, the study also investigated the available daylight on the work plane for overall building lighting, heating and cooling energy. The study was therefore able to demonstrate a linear relationship between cooling energy consumption and the over-lit area. (Chi *et al.*, 2018) and therefore recommended that confining over-lit areas to less than 40% in the south zone of a building and less than 50% in the north, east and west zones could limit overall energy use intensity to less than 120 kWh/m^2/year within the warm and temperate climatic region of Seville, Spain.

The technical feasibility of utilising daylight for lighting energy efficiency was clearly demonstrated in both studies reviewed in this section. However, the approach of using daylight for electrical energy saving and the possible consequence of excessive daylighting was the focal point of this appraisal. Daylight-linked control would therefore be required to achieve lighting energy savings due to daylight. In this sense, the electric lighting energy consumption is determined by the available daylight level. The review of additional studies on the contribution of daylight toward energy savings is covered in the next section. Daylighting design poses the risk of overheating during the summer season and glare in the winter season due to the low-angle sun rays. Both effects can lead to excessive energy usage for space cooling and lighting, thereby defeating the overarching goal of design optimisation for daylighting.

As a background study for this research, Lim *et al.*'s (2017) research provides the daylighting energy saving principle that was adopted in this research, while Chi *et al.* (2018) provided an understanding of the consequence of over-lit space, which thus guided the analysis for areas of the case study building with excessive solar exposure.

2.5 Estimating Energy Savings of Lighting Interventions

Most building owners or businesses are motivated to adopt effective daylighting interventions once proven to reduce energy consumption and related utility costs (Krarti *et al.*, 2005 and Lee *et al.*, 2018). Estimation of energy savings of lighting interventions is therefore crucial in promoting lighting energy efficiency through daylighting optimisation or occupancy monitoring. Yu *et al*. (2015) demonstrate the estimation of potential energy saving from daylight using field measurement, software simulation, empirical formulae and estimation algorithms. Field measurement involves the use of photometric sensors and energy meters to quantify the energy savings of daylighting in a building. The study indicates that due to the expense and duration required for field measurement, extrapolated data for a one-year cycle of local weather conditions can be adopted.

In a previous study, Atif and Galasiu (2003) adopt field measurements to investigate daylight impact and electric lighting usage of two atrium buildings. An image of one of the buildings is presented in Figure 2.6 (a). Their study questioned the common hypothesis that ground floors in atrium-lit buildings receive sufficient daylight to effectively displace electric lighting. Two daylight-linked control systems, continuous dimming and automatic on/off were used to monitor the daylighting energy performance of two case study buildings in Canada. For selected months in winter and summer, indoor horizontal illuminance was monitored at strategic indoor spaces in both buildings. The approach yielded data around 25 test points daily from 7h00 to 19h00 under automatic on/off lighting control and 39 test points under continuous dimming lighting control. Night-time lighting illuminance was also monitored and used to obtain the actual daylight contribution by subtracting day-time illuminance from night-time illuminance. In both buildings, electric light burning hours and power profiles were monitored as well in winter and summer seasons.

The study found that horizontal illuminance at ground floor perimeter areas was above 200 lux between 9h00 and 13h30 in winter and mostly above 500 lux between 9h00 and 17h00 in summer. In both seasons, the illuminance of areas that are 3.5 m away from the perimeter was below 200 lux during the same period. The study concluded that continuous dimming light control was the most viable lighting energy savings technique. During the occupancy period (08h00 to 18h00), the study found that continuous dimming daylight-linked control resulted in 60% lighting energy savings in winter and 74% in summer. The study attributes the poor performance of automatic on/off lighting control to the oversized lighting system of the building and built-up snow on the glazed roof. Based on the findings, the study further argues that daylight distribution in buildings and the type of automated lighting control are crucial for daylight-linked energy savings.

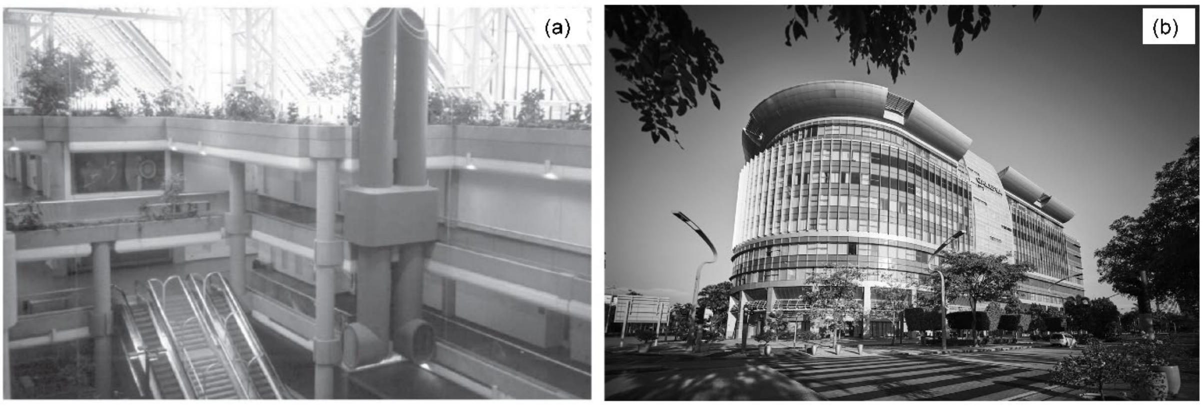


Figure 2.6: Daylight-linked automatic lighting control: (a) atrium building in Quebec City, Canada (Atif and Galasiu, 2003:443) and (b) passive solar design office building in Kuala Lumpur, Malaysia (Lim *et al.*, 2017:169)

As discussed in the previous section, Lim *et al.* (2017) adopted field measurement to explore the energy saving potential and occupants' behaviour towards daylight-assisted task lights in two office buildings in Malaysia. Due to limited monitoring equipment, the study monitored the office buildings for two consecutive months (September and October 2015). The approach was motivated by the fact that sky conditions in Malaysia are usually intermediate for 85.6% and overcast for 14.0% of the time. Based on local weather and long-term climatic data, there were no significant variations in overcast and rainy days for both months. The study used Hobo-U12 loggers to monitor daylight and electric lights' illuminance while the electric light energy consumption was derived through LPD (installed lights wattage divided by floor area) (*ibid.*).

Software-based simulation is commonly applied in studies evaluating building daylighting and potential energy savings. However, Yu *et al.* (2015) argue that, despite the shorter period in software simulation, its accuracy is a major concern and should be validated through measurements in order to ensure reliable outcomes. The study adds that simulation is instrumental in the early design phase when daylighting features of buildings can be manipulated for optimised outcomes. Some of the commonly used software applications are EnergyPlus (Lee *et al.*, 2018), DaySim (Akimov, De Michele, Filippi Oberegger, Badenko and Mainini, 2021), DOE-2.1 (Asif Ul Haq, Islam, Shihavuddin, Maruf, Al Mansur and Hassan, 2020), IES-VE (Freewan and Al Dalala, 2020) and Autodesk Revit (Kota, Haberl, Clayton and Yan, 2014).

Several studies are also based on empirical formulae derived from prior/historical studies and commonly applied in building lighting standards (Yu *et al.*, 2015). For example, the European Standards En15193 (European Committee for Standardisation, 2017) provides a calculation method for indoor lighting energy requirements relative to daylight. Lastly, estimation algorithms are manual calculation procedures computed by researchers for fast and accurate daylight potential energy saving (Yu *et al.*, 2015). Some of the algorithms highlighted by the study are "*calculation using the cumulative frequency distribution of daylight illuminance, calculation using mathematical integration, calculation algorithm of artificial light output by considering the contribution from other luminaires and calculation based on the property of daylight responsive dimming system*" (*ibid.,* 2015:500).

Quantifying electric light energy savings due to daylight is quite complex because both concepts use different energy sources. In addition, effective daylight in a building is influenced by several factors such as tasks, building design, ambient sun ray blockage, local weather conditions, human factors, and floor arrangement. As highlighted by Yu *et al*. (2015), field measurements, software-based simulation, empirical formulae, calculation, and estimation algorithm are some of the basic approaches used for estimating lighting energy savings due to daylighting. The experimental aspect of this research is based on field measurement, while a software-based approach was adopted to evaluate and quantify the whole-building daylighting distribution and energy performance.

2.6 Conclusions

Based on the studies appraised in this Chapter, daylighting design strategies, weather and surrounding obstacles were identified as the main influencing factors of daylighting in buildings. Side-lighting and top-lighting emerged as the two fundamental daylighting design strategies in buildings. Although top-lighting was deemed the best daylighting strategy, it is not encouraged in climates with a high cooling load. One of the key insights on lighting energy efficiency is that replacing inefficient light fixtures such as T8 fluorescent tubes with T5 fluorescent tubes or LED constitutes a substantial intervention. However, such measures pose a performance and investment risk for ESCos in performance contracting projects. It was also clear that integrating energy efficient lights with occupancy-based or daylight-linked control systems increases lighting energy savings. However, occupancy-based sensor operating mechanisms (on/off and dimming), response time, and occupancy rate significantly influence the amount of energy reduction. Dimming of task, surrounding, and background area lights were revealed to have the most energy savings performance while also ensuring visual comfort of occupants compared to on/off control devices.

In addition, the reviewed studies highlight that the integration of daylight in a building does not automatically constitute energy saving without daylight-linked control. The negative impact of daylighting, such as glare and overheating due to inappropriate design, was also highlighted in several studies. In quantifying daylighting and potential energy savings performance, some of the methods recommended in some of the studies include field measurement, software-based simulation, empirical formulae and estimation algorithms.

CHAPTER 3

METHOD OF THE STUDY - BUILDING DAYLIGHT LEVEL MEASUREMENT, ENERGY PERFORMANCE ESTIMATION AND SIMULATION

3.1 Introduction

A quantitative research approach was adopted for this study. According to Kruisselbrink, Dangol and Rosemann (2018), measurement of daylight levels in a building can be based on spot or continuous methods. In the spot method, a measurement grid covering the overall lighting space is established. Gentile, Dubois, Osterhaus, Stoffer, S., Amorim, C.N.D., Geisler-Moroder, D. and Jakobiak (2016) suggest that spot measurement of daylight level should only focus on relevant task areas for simplicity and reduced cost.

Unlike spot measurement, continuous methods span over a long period and involve dividing the space into daylit zones (Kruisselbrink, Dangol and Rosemann, 2018) or area of interest. The area of interest is determined by the proximity from the perimeter walls but is usually set at 0.5 m from the perimeter wall. The study recommends that at least one measurement point should be located at the working plane level for continuous daylight measurement in an office space. In addition to measurements, Yu *et al.* (2015) highlights software simulation, empirical formulae and estimation algorithms as key approaches used to estimate the energy savings potential due to daylight. This study adopted a continuous method for the experimental daylight level measurement for a heritage category A3 building. Field measurement and software-based simulation were also used to compute the potential for optimised energy savings due to the difference in energy consumption levels between “as-is” versus performance after daylighting interventions.

This Chapter therefore presents the procedure and instrumentation adopted in the continuous field measurements and software-based simulation of the building daylighting and energy performance. To this effect, the Chapter also presents the building description as well as the experimental and simulation-based approaches used. This is followed by a discussion of electric lights and appliances in the building and mathematical formulae used in quantifying the lighting energy performance of the building.

Figure 3.1 presents an overview of the overall research process, while Table 3-1 presents a summary of primary data needed, collection tools, presentation, and analyses, as well as sources of secondary data used in the study.

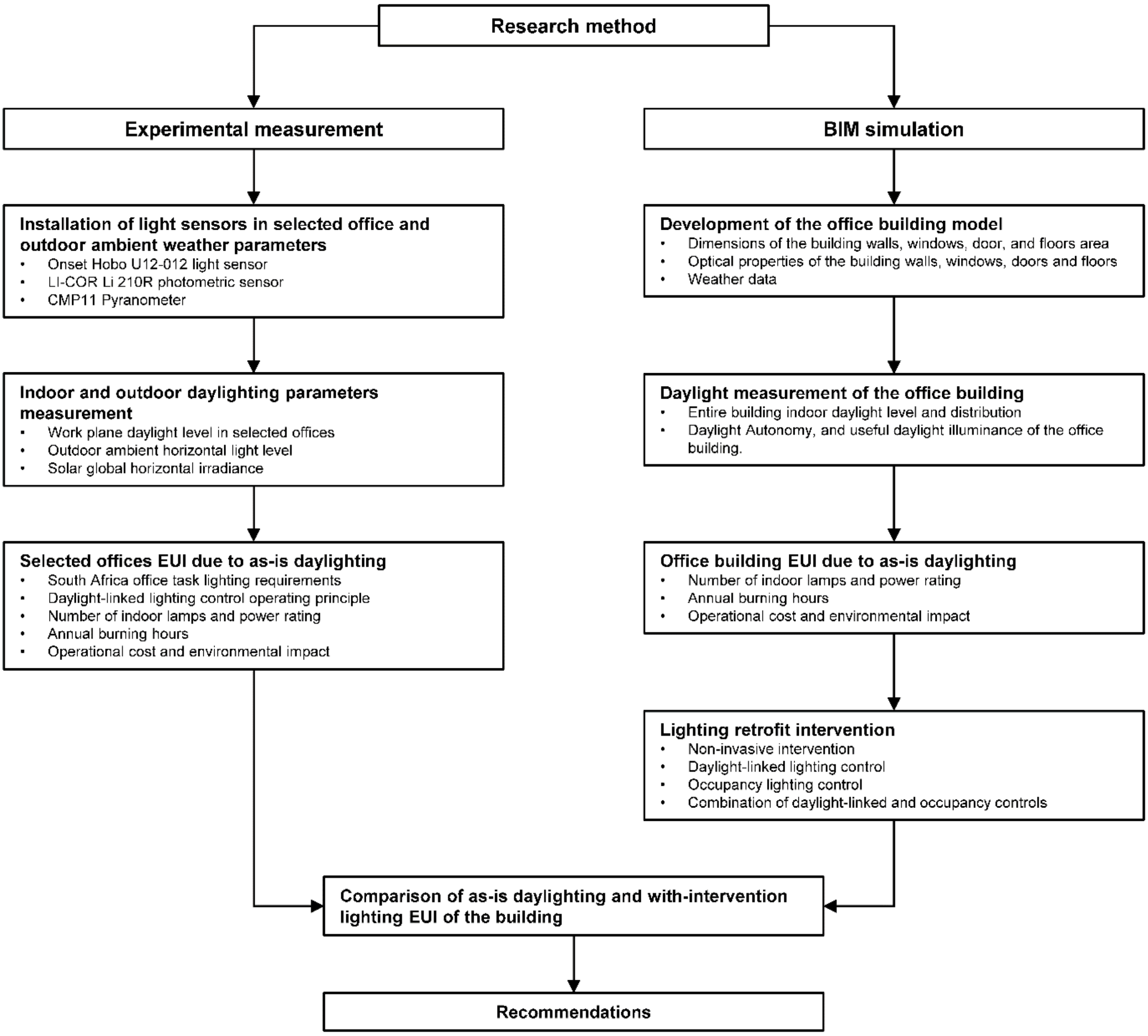


Figure 3.1: Workflow of the research process

Table 3-1: Summary of data needed, collection tools, and analyses relative to the main research question

Research question	Data collection tools and process	Data analysis approach
Sub-question 1: What is the status quo EUI for the selected case study building?	**Primary data**: The floor area of selected offices was measured to compute the "as-is" lighting energy consumption of the case study building. IES-VE application was used to simulate the entire building "as-is" EUI, and the dimensions of the building walls, windows, doors, and floor area were used to develop the building model. **Secondary data:** The power ratings on the nameplate of the installed lamps in the offices and their annual burning hours were also used. The various offices' occupant class schedule was used to determine the burning hours of the selected office and used to extrapolate that of the entire building.	The light energy consumption was computed by multiplying the number of lamps in the selected offices by their wattage and annual building hours. The building model, in-built weather data of the building location and schedule operation hours, lighting and appliances were used in the IES-VE application to simulate the "as-is" EUI of the entire building. The selected offices' energy consumption and whole-building EUI were presented and analysed using bar and pie charts. Tables were also used to summarise the findings. The findings were compared with published academic findings for justification. The graphic representation of the data and analysis were presented and analysed in Chapter 4.
Sub-question 2: What are the key daylighting interventions of the case study building?	**Secondary data**: Non-invasive lighting interventions were considered in this research. The implemented interventions are daylight-linked control, occupancy control, and a combination of both controls.	The lighting interventions were implemented using the IES-VE, guided by the typical daylight-linked control principle from literature studies. The impact of the lighting interventions were demonstrated with the daylight level and EUI of the building. Both parameters were presented in line graphs and bar charts. A comparative analysis between "as-is" and with intervention EUI was also tabulated. Sub-findings and graphs of the key lighting interventions were covered in Chapters 4 and 5.
Sub-question 3: What is the "as-is" contribution of daylighting to the EUI of the building?	**Primary data**: Onset HOBO U12-012 photometric sensor was used to monitor the indoor daylight level in selected offices in the building. The influence of the outdoor ambient weather conditions was also measured. Likewise, the installed lamps in the offices were counted to deduce the building's lighting energy savings due to daylighting. **Secondary data**: Daylight-linked lighting control principle was assumed from literature studies to operate the indoor electric lights in the offices with respect to measured indoor daylight level.	The measured indoor daylight level of the offices, as well as the outdoor ambient daylight horizontal illuminance and solar global horizontal irradiance, were presented and analysed using line graphs mainly. Simulated daily movement of the sun, solar exposure, luminance and illuminance distributions, and photos of the building was also used to depict the daylighting of the building. Lastly, bar, pie charts and tables were used to analyse the computed selected offices' lights energy consumption and the simulated EUI of the entire building. Analysis and sub-findings of daylighting contribution to the building EUI were presented and discussed in Chapter 4.
Sub-question 4: What is the potential lighting retrofit interventions towards reducing EUI, and what would be the viability of such interventions?	**Primary data:** The IEV-ES application was used to implement the lighting retrofit interventions. Thus, the dimensions of the building, as explained above, were used to develop the building model. **Secondary data**: The daylight-linked and occupancy lighting control operating principles were obtained from literature studies. The IES-VE application building materials thermal-optical properties database was used to assign optical properties to the building.	The operational cost and environmental impact were deduced using the current energy tariff of the university and local coal-fired power plant emission factors. Simulated daylight profiles of the building were presented in line graphs. Average daylight luminance, illuminance, daylight autonomy, and useful daylight illuminance were used to analyse the light retrofit interventions of the building. Also, simulated EUI of the building was presented in bar and pie charts. The "as-is" and with-intervention EUI were compared using bar charts and tables. The analysis and discussion of the results were covered in Chapters 4 and 5.
Main research question: What is the contribution of daylighting towards EUI-reduction in heritage Place-of-Instruction buildings in South Africa, and what are the possible lighting interventions towards reducing EUI and enhanced financial and environmental benefits of such buildings under energy zone 4 as per the 2nd edition of SANS10400-XA criteria?		The main research question was answered by answering all the sub-questions. The sub-findings and analysis, as well as the discussion of results, were presented in Chapters 4 and 5. Overall findings in response to the research question are consolidated in Chapter 6.

3.2 Description of the Case Study Building

Livingstone Hall, located at the University of Fort Hare in Alice, is used as a case study in this research. Although several departments are based in the building for their respective academic activities (Geology, Physics, Computer Science and Mathematics), the study focuses mainly on the Physics Department section of the building. In reference to EPC regulations, the building falls under category A3 (place-of-instruction) (South African Bureau of Standards, 2021). In addition, the building was built more than 90 years ago (completed mid-1930s) and is thus considered a heritage building under the Heritage Resources Act (South Africa Heritage Resources Agency, 1999). Photos of the Physics Department are presented in Figure 3.2.

Figure 3.2: The Physics Building at the University of Fort Hare; (a) front view and (b) rear view

The Physics Department occupies a two-story portion of the building, with the front view shown in Figure 3.2 (a) and the rear view in Figure 3.2 (b). During the period of this research, the building consisted mainly of laboratories, lecture halls, single offices and shared offices on both floors. Technical details of the building, such as the floor plans, facades and solar exposure analysis, are presented graphically and discussed in Sections 3.3.2 and 5.2.1.

3.2.1 Data needed, collection and analysis approaches

As highlighted in the previous section of this Chapter, for the experimental approach, photometric sensors were installed in selected offices in the building to monitor the indoor light levels, while Integrated Environmental Solution-Virtual Environment (IEV-VE) software was used for the simulation approach. For simulation inputs, the building dimensions and envelope properties were used to develop a model of the building as required for simulation. Even though the use of both approaches simultaneously was not intended for comparison of outcomes, the simulation-based approach facilitated a holistic daylighting analysis as well as whole-building energy performance evaluation, while on the other hand, experimental measurement was used to obtain real-time daylight levels of a selected sample of offices in the building due to limited sensors.

3.2.2 Overview of the Installed Instrumentation

The University of Fort Hare is located in the town of Alice, Eastern Cape, at latitude 32°47’7” S and longitude 26°50’43” E, and at 540m above sea level. Alice is located within energy zone 4 of South Africa as per SANS10400-XA (South African Bureau of Standards, 2021). GIS imagery of the University of Fort Hare, Livingstone Hall and a photo of the Physics Department (building) are presented in Figure 3.3

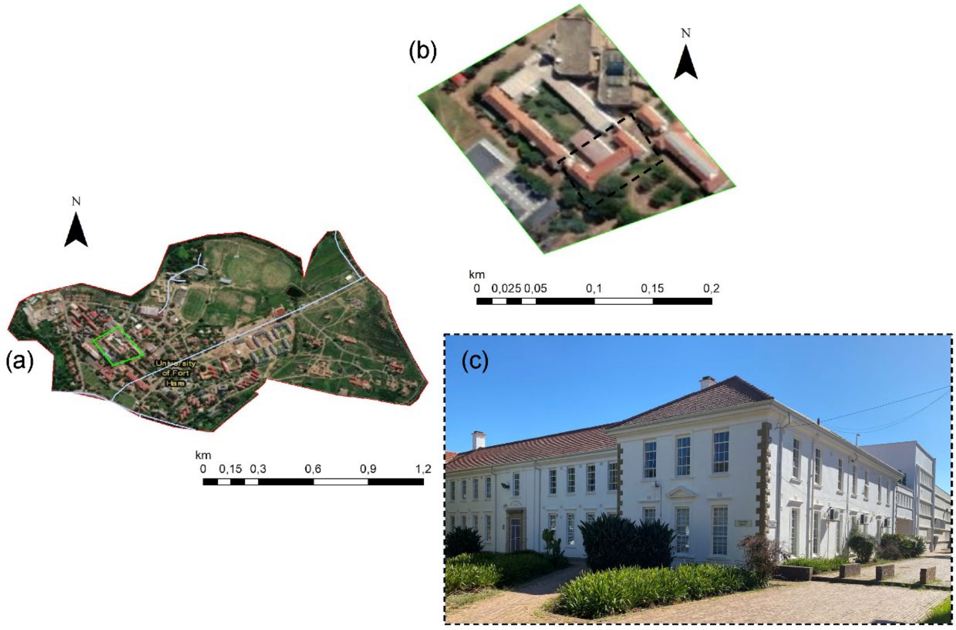


Figure 3.3: GIS imagery of the University of Fort Hare, Alice in Eastern Cape (a); imagery of Livingstone Hare at the University of Fort Hare, and a photo of the Physics Building

In the experimental aspect of the research, the indoor daylight level, ambient daylight, and solar global horizontal irradiance were measured using Onset HOBO U12-012 photometric sensor, LI-Cor LI-210R photometric sensor, and Kipp & Zonen CMP 11 pyranometer, respectively. The HOBO U12-012 and a solar weather station set-up are shown in Figures 3.4 and 3.5, respectively.

Figure 3.4: Onset HOBO U12-012 Temp/RH/Light/Ex sensor

Figure 3.5: Solar radiation and weather station at the SolarWatt Park, University of Fort Hare

In the absence of dedicated submetering for the building or lighting energy use, the lamps in each office and other parts of the building were physically counted in order to estimate the “as-is” lighting energy consumption of the building. The lamps' wattage and annual burning hours were also taken into consideration. Lastly, the dimensions of the building walls, windows, doors, and floor area used for modelling the building were measured using a measuring wheel and tape.

Secondary data used in the research include the lighting requirements for typical office tasks in South Africa as stipulated in the Department of Labour (1993). Daylight-linked lighting control operating principles used to simulate the operation of the electric lights in the offices were distilled from existing studies. The inscribed power rating of the lamps was used together with the number of lamps and annual burning hours to determine the lighting energy consumption of selected offices in the building. In terms of the whole-building EUI simulation, the class timetabling, and typical staff schedules were used to establish the annual burning hours based on typical class schedules. The inscribed power rating and the burning hours were therefore part of the secondary data used in the research.

GHG emissions factor for coal-fired power generation in South Africa and the energy tariff structure used to deduce the environmental impact and operational cost, respectively, were obtained from Eskom (2020) and Eskom (2021). The selection of optic properties of building envelope components from the in-built IES-VE database was guided by insights from the studies reviewed. The web-based weather database in the IES-VE application was used to simulate the building's daylighting and energy performance. This information from the IES-VE database, as used in building modelling and simulation, also form part of the secondary data for the study.

3.3 As-is Daylighting of the Case Study Building

3.3.1 Experimental approach

Continuous measurement (as substantiated in Kruisselbrink *et al.*, 2018) was adopted to evaluate the "as-is" daylight levels of the building. However, only a purposely selected sample of single offices was covered in this experiment due to the limited number of photometric sensors. The offices considered were strategically selected to ensure that the daylighting performance was sufficiently sampled and represented in terms of the daily trajectory of the sun for both summer and winter seasons. As shown in Figures 3.6 and 3.7, three office spaces on each floor (two offices on the west and three offices on the east) were selected for the study.

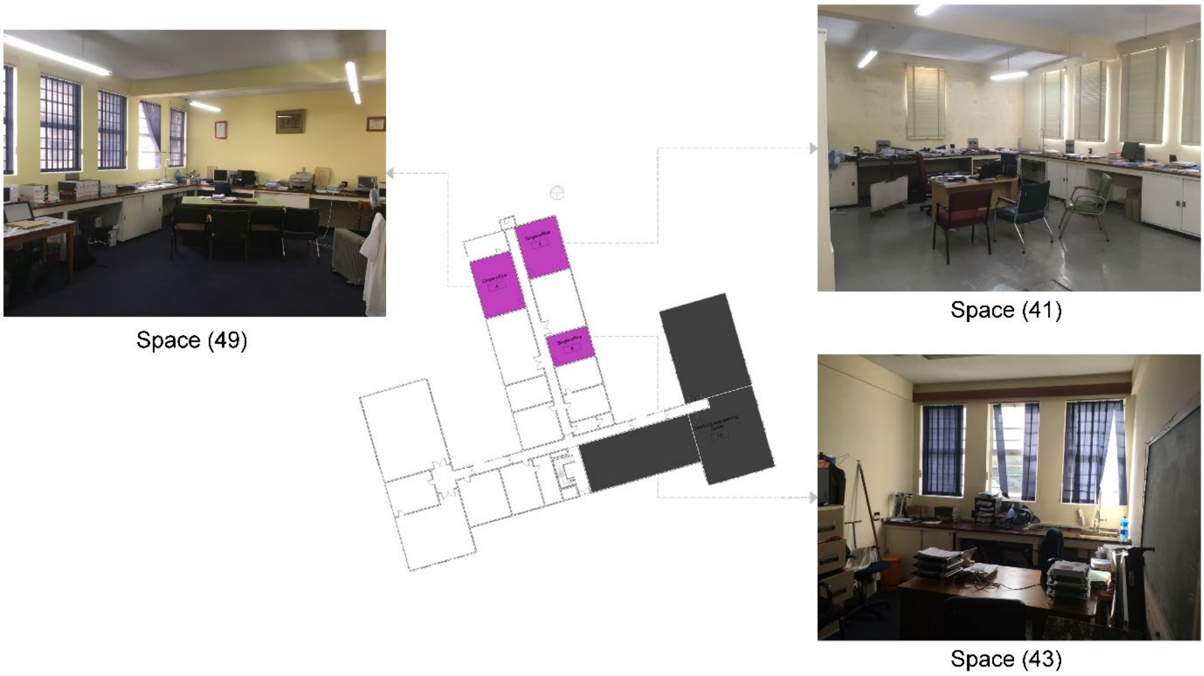


Figure 3.6: The ground floor layout of the Physics building indicating selected offices.

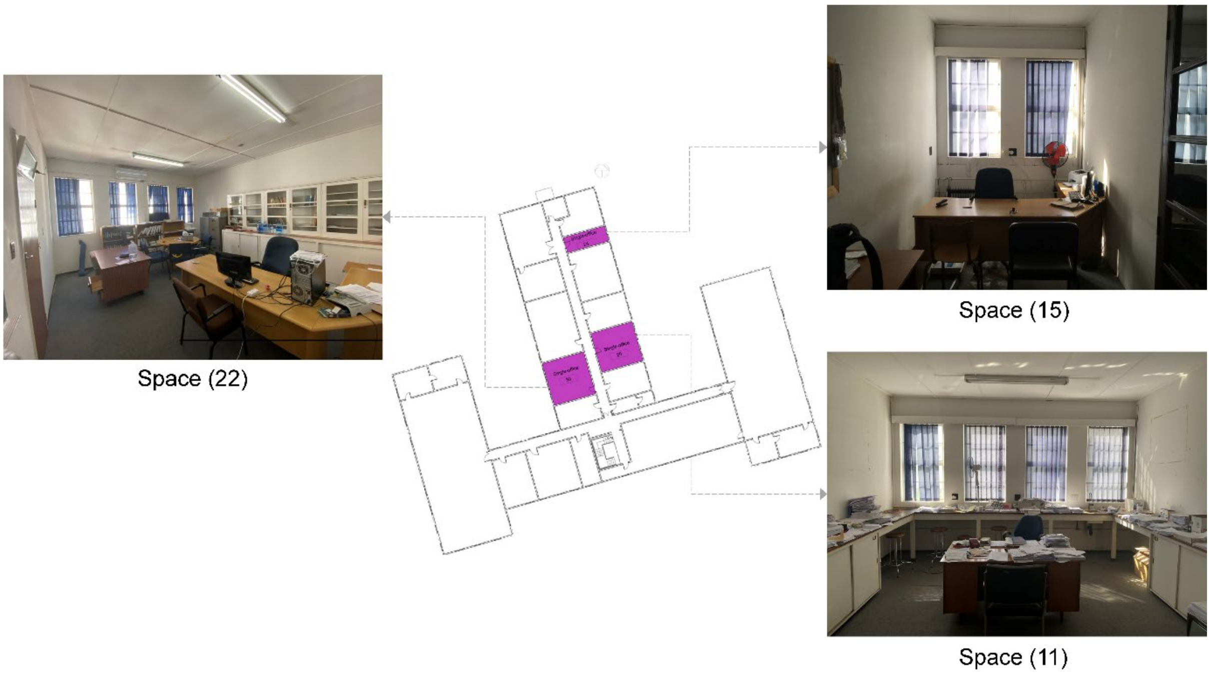


Figure 3.7: The top floor layout of the Physics building indicating selected offices

The offices have different floor arrangements with varying distances of desks from the widows. The average distance of the desk from the windows in the selected offices is 4.50 m, with the longest distance at 6.50 m in space 22. Figures 3.6 and 3.7 also show that most of the offices use vertical fabric (blue) blinds, while venetian aluminium blinds were installed in space 41. For purposes of the "as-is" study, occupants were not constrained on how to operate the blinds or lights. Instead, daylighting levels were evaluated under actual operating conditions by the users/occupants. In line with Kruisselbrink *et al.* (2018), daylight levels at offices' desks as the work plane were targeted in the experiment. The Onset HOBO U12-012 Temp/RH/Light/Ex sensor was placed on the desk of the selected offices. The HOBO U12-12 sensor is designed for indoor light measurement, ranging from 1 lux to 48 438 lux (Onset, 2018). The sensor is powered by a 3V button battery and has in-built memory capable of storing up to 43 000 measurements (see Figure 3.4 for a photo of the HOBO U12 sensor used in this experiment). The measurement was conducted from April to July, where April and May were considered as (late) summer season, while June and July represent the winter season. The data were logged in 30 minutes intervals and downloaded every fourth week.

In addition to the selected offices, light level measurement, outdoor ambient solar radiation and horizontal illuminance were measured. The outdoor ambient solar radiation was used to establish clear and cloudy sky conditions to allow for indoor daylight analyses relative to available outdoor ambient horizontal illuminance under clear and cloudy sky conditions. Data from the solar weather station at the SolarWatt Park (see Figure 3.8) at the University of Fort Hare were also used to achieve this objective.

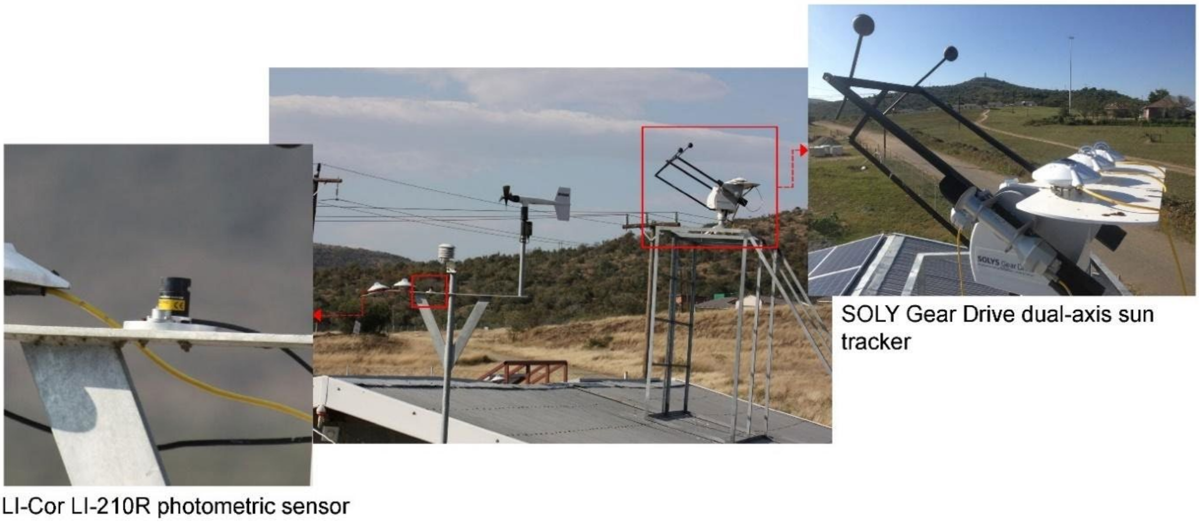


Figure 3.8: Solar weather station at the SolarWatt Park, University of Fort Hare

The SolarWatt Park is less than 500 m from the case study building. The weather station entails a SOLY Gear Drive dual-axis sun tracker, which houses a pyrheliometer, shaded pyrgeometer, pyranometer, and a shaded pyranometer. The pyrheliometer is used to measure direct normal irradiance (DNI), the shaded pyrgeometer measures downward longwave radiation, global horizontal irradiance (GHI) and direct horizontal irradiance (DHI) are measured with the pyranometer and the shade pyranometer, respectively. In addition, an LI-

Cor LI-210R photometric sensor was also installed at the weather station to monitor outdoor horizontal illuminance. The specifications of the radiometers are summarised in Table 3-2.

Table 3-2: Radiometers specifications (Overen, Meyer and Makaka, 2021)

Radiometer	Sensitivity	Spectral range	Response time
Pyranometer	5 – 10 μV/W/m^2	0.3 – 2.8 μm	<5s
Li-Cor LI-210R	30 μA/100 klux		<1 μs

The specifications of the pyranometer and Li-Cor LI-210R used for GHI and HDI measurement are necessary to show the reliability and measurement range of the sensors. The specifications are also used to validate the reported data and findings.

3.3.2 Simulation approach

One of the shortfalls of the experimental approach is the limited number of spaces covered due to insufficient sensors. A simulation approach was therefore adopted to analyse the whole-building daylight distribution. A walk-through audit of the building was conducted to obtain the dimensions of the building envelope components, which served as inputs for developing the building model. Autodesk Revit 2021 was used to capture the model, which was then exported to IES-VE, where it was fully developed as the key input for simulation. The Autodesk Revit drawings of the floor layout of the building are presented in Figures 3.9 and 3.10.

Figure 3.9: The ground floor layout of the Physics building at the University of Fort Hare

Figure 3.10: The top floor layout of the Physics building at the University of Fort

The building is oriented 164°S and has a total floor area of 1 170.44 m^2. This includes the Teaching and Learning Centre, which is outside the scope of this research. Moreover, the floor area of the various rooms on both floors varied. The average height of the rooms on both floors was 3.00 m. Figure 3.11 shows the various elevations of the building.

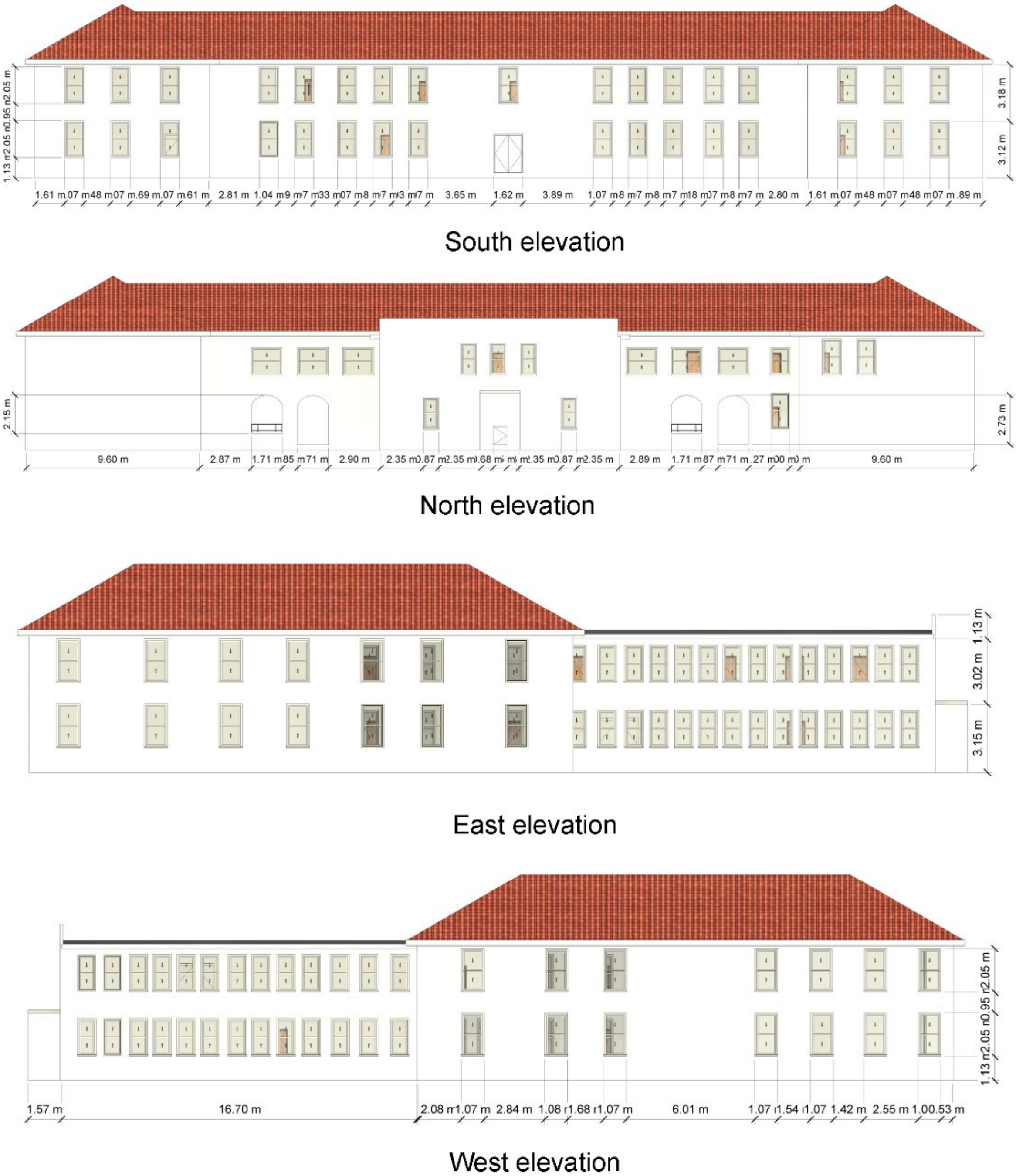


Figure 3.11: The various elevations of the building

According to Bradshaw (2006:279), the size, position and orientation of windows are important factors that influence the daylight levels in a building. The sizes and positions of the windows in the Physics Department building were therefore noted as part of the data for the study. As shown in Figure 3.12, all the windows are on the various facades (vertical windows) but no roof windows (skylight, clerestory or monitor windows). The windows were also noted to be of two main sizes, as shown in Figures 3.12 (a) and (b).

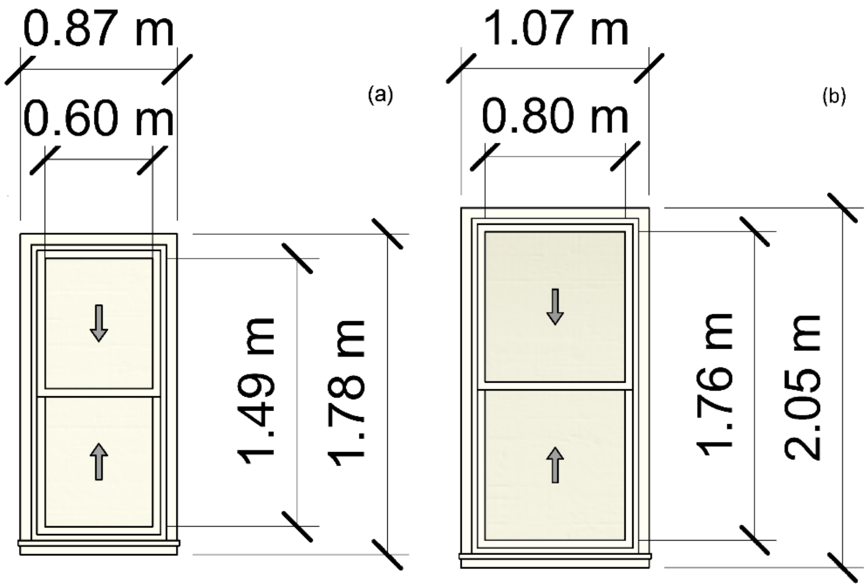


Figure 3.12: The two main window sizes in the building; (a) small and (b) large

Windows in both sizes were made of steel frames with a white-paint finish on inner and outer surfaces. The large windows have an average glazing area of 1.00 m^2 and are mostly used on the south elevation where the laboratories and lecture halls are located. The east and west elevations, where most of the offices are situated, mainly use small windows with an average glazing area of 0.80 m^2. In addition to the large and small windows, another set of windows with an average glazing area of 1.5 m^2 was installed on the top floor of the north elevation, as shown in Figure 3.11.

Glazing for all the windows is single pane 6 mm clear glass. The assumed properties of the windows are presented in Table 3-3. The glass was also assumed to be isotropic in behaviour, i.e., the properties shown in Table 3-3 apply to both sides of the glass.

Table 3-3: Thermophysical properties of glass as adapted from IES-VE building material properties database

Glass type	**Soda-lime**
Thickness	6 mm
U-value	3.76 W/m^2K
Emissivity	0.84
Young's modulus	70.0 ×103 MPa
Specific heat	1.0 ×103
Reflectance	0.072
Reflective index	1.53

The IES-VE 3D SunCast model of the building is presented in Figure 3.13.

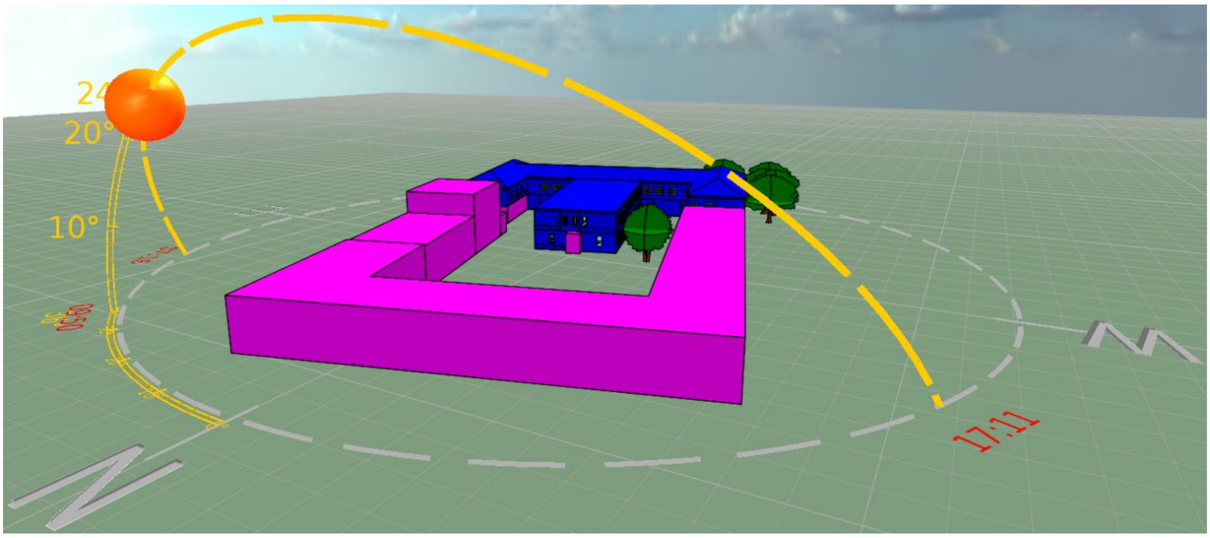


Figure 3.13: A 3D SunCast model of the case study building on the 15 July

As shown in Figure 3.13, the building model includes adjacent buildings (pink structures) and trees that could be potential sun blockades due to their proximity and height. Bisho weather data was used in the simulation since the Alice weather data is not in the IES-VE weather database. However, Bisho is approximately 70 km away from Alice, and both towns are categorised under energy zone 4 (South African Bureau of Standards, 2021). Further, parameters such as solar exposure, luminance, illuminance, daylight factor, useful daylight illuminance and special daylight anatomy were employed to analyse the whole-building daylighting performance in Chapter 4 of this report.

3.4 Lighting Energy Performance of the Building

3.4.1 Electric lights and appliances in the building

The walk-through audit of the building also covered electric lights and appliances. In the audit, the number and nameplate power ratings of the lights and appliances in the respective spaces of the building were obtained. The data collected were used to calculate the light energy consumption of the selected offices and also as input into the building model to simulate the EUI of the entire building. During the audit, electronic and magnetic fluorescent fixtures were noted to be the most common. The fixtures used were Hyundai YZ-T5-3-band 35W 6400 k tubes, while Osram Eco ST8E-1.5m 20W tubes were used for the magnetic fixtures. Photos of the Figure 3.14 shows the types of fluorescent tubes used in both fixtures.

Hyundai YZ-T5-3-band fluorescent tube Osram Eco ST8E-1.5m fluorescent tube

Figure 3.14: Electronic and magnetic fluorescent tubes used in the building.

A total of 332 fluorescent tubes were recorded in the audit. The inventories for ground and top floor lights and appliances are presented in Appendix A-1 and A-2, where an average of one desktop or laptop personal computer was noted for the single offices. A projector was installed in each of the lecture halls. Several electrical equipment and devices were also noted in the laboratories. However, all the laboratory electrical equipment was grouped as lab apparatus for simplicity in modelling and simulation. It was also noted that the building has no central heating, ventilation or air conditioning system, although there were standing fans, heaters and split-unit air conditioners in some offices.

3.4.2 Occupancy and operating hours

The energy performance of the building was achieved based on calculation and simulation due to the lack of dedicated-metering energy data. A crucial aspect of calculating and simulating the energy performance was to establish the building occupancy period, lights and time-of-use of appliances. The normal occupancy schedule of the building before the Coronavirus (Covid-19) outbreak was assumed based on the Faculty of Science and Agriculture 2018 prospectus that contains the class schedules for the building. The class schedule was then used to estimate the lecturers' and students' occupancy periods, as well as the operating hours for lights and appliances.

3.4.3 Estimation of lighting energy for Selected offices

The field measurement approach (Yu *et al.*, 2015) was adopted in estimating the lighting energy savings due to daylight in the selected offices. In this approach, the electric lights in a given space are controlled with a daylight-linked sensor. The energy saved while the electric lights are switched off by the sensor as a result of sufficient daylighting in the space is, therefore, the energy savings due to daylight (Lim *et al.*, 2017). The same principle was adopted in the experimental evaluation of the light energy savings due to daylighting in the selected offices, even though daylight-linked sensors were not installed. Equation 1 was therefore used to determine the electric light energy consumption.

$$\varepsilon_{lit} = \sum_{l=1,2,3...,n}^{n} \left(\chi_{l_1}\mu_f + \chi_{l_2}\mu_f ... + \chi_{l_n}\mu_f \right) \tag{1}$$

Where ε_{lit} is the total electric light energy in a given space (kWh), χ_l is the nameplate power (W) rating of the lights, μ_f is the time in hours the lights are switched on, and n is the total number of lights in a given space. From Equation (1), the operational cost of the selected offices due to electric lights was derived using Equation (2).

$$\chi_R = \varepsilon_{lit} \times \frac{\alpha_t}{100} \tag{2}$$

where χ_R (R) is the daily operational cost of the selected offices due to electric lights usage, while α_t (c/kWh) is the energy tariff. The energy tariff is given by the national utility and varies with consumers, transmission, time of use, and season.

The light energy savings due to daylight in the selected office was therefore derived by assuming the effect of a daylight-linked sensor. That is, the sensor switches off the lights when the indoor illuminance is equal to or greater than 300 lux and on during occupied hours when the illuminance is below 300 lux (the light level benchmark for conference rooms and general office tasks in South Africa). In this case, the daylight-linked controlled electric light energy consumption can be denoted as β_{lit} (kWh) and derived as shown in Equation (3).

$$\beta_{lit} = \sum_{l=1,2,3...,n}^{n} \left(\chi_{l_1}\mu_f + \chi_{l_2}\mu_f ... + \chi_{l_n}\mu_f \right) \tag{3}$$

The average daily electric lights energy savings due to daylighting is given as shown in Equation (4);

$$\phi_{sav} = \varepsilon_{lit} - \beta_{lit} \tag{4}$$

The higher the value of ϕ_{sav}, the better the daylighting performance of the offices. If ϕ_{sav} equal to zero, it implies that the daylight level in the offices cannot be utilised for typical office tasks. By replacing ε_{lit} with ϕ_{sav} in Equation (2), the financial benefit due to daylighting was obtained.

3.4.4 Whole-building energy use intensity simulation

The energy-use profiles based on the use-periods as discussed in Section 3.4.2, as well as the lights and appliances wattage in Appendix A-1 and A-2, were entered into the building model in the IES-VE application for simulation. The simulation was set to analyse the whole-building energy for a full year while recording the data in 30 minutes intervals. Once completed, a second energy profile with the daylights' interventions was loaded into the model with a different title but simulated with the same settings. The "as-is" EUI of the building was obtained from the initial simulation, while the optimised EUI was generated from the second simulation.

3.5 Data Collection, Presentation, Analysis, and Discussion

Data collection in this research was guided by the sub-questions in order to achieve the objectives of the study (refer to Chapter 1, Section 1.6). The above sections highlighted the key activities and procedures used in collecting primary and secondary data. Secondary data were sourced from journal articles by Yu *et al.* (2015) and Roisin *et al.* (2008), which provide detailed approaches for implementing simulation-based lighting energy efficiency intervention in a building. The articles therefore served as secondary data sources towards addressing sub-question 4. Similarly, the IES-VE in-built building materials properties database was adopted as a source of secondary data for simulating the "as-is" and optimised whole-building daylight distribution and EUI as needed in sub-questions 1, 3, and 4. The walk-through audit presented in Section 3.4.1 was another vital source of secondary data used in addressing sub-question 1, 3, and 4 as well. Other sources of secondary data are the University of Fort Hare, Faculty of Science and Agriculture 2018 prospectus, and the Eskom tariffs & charges booklet 2021/22 (Eskom, 2021).

In terms of data presentation, collected data pertaining to all sub-questions were visualised using line graphs, pie charts, bar charts, and 3D models of the building and presented in Chapters 4 and 5 of this report. Tables summarising analysed or computed data were also adopted. The daylighting performance of the building was analysed using parameters such as luminance, illuminance, daylight factor, useful daylight illuminance and spatial daylight autonomy. Average space wattage and EUI were used to analyse the energy performance of the building. The operational cost of the building relative to energy usage and environmental impact were analysed with energy cost in Rand and greenhouse gas emissions such as CO_2.

Data presentation and analysis for sub-questions 1, 2, and 3 were covered in Chapter 4, while Chapter 5 covers data analysis for sub-question 4. In both Chapters, the analysed data were discussed in terms of the reasons and physical implications of the data pattern. The discussion also draws a comparison of the obtained data with other similar published findings. A summary of the data collection, presentation, analyses and discussion was presented in Table 3-1.

3.6 Ethics Consideration

All the data collection processes and tasks were conducted in line with the guidelines on ethics in research by the University of the Witwatersrand. Permission from the relevant authorities of the University of Fort Hare was obtained to install data acquisition systems in the building and to gain access to the building for data collection periodically. In addition, the occupants of the offices were duly informed and gave their consent before the photometric sensors were deployed as well as any other measurements. As agreed with the occupants, none of their personal information or activities was disclosed in this report or in any future publications. Lastly, in line with the ethics waiver obtained for the research, no human participation in the form of a questionnaire or interview was involved in the research

CHAPTER 4

AS-IS DAYLIGHTING AND POTENTIAL ENERGY SAVINGS OF THE BUILDING

4.1 Introduction

Furthermore, several metrics have been adopted over the years to assess daylighting in a building. According to Yu *et al.* (2015:495), daylight illuminance (lux) is the most commonly used metric for evaluating the daylight performance of a building. Daylight illuminance is often used together with luminance (cd/m^2) (Szokolay, 2008). Illuminance is measured horizontally at a given work plane and daylight zone or area of interest (AOI) to determine workplace light level requirements (Kunwar, Cetin, Passe, Zhou and Li, 2020). The work plane is equivalent to the height of an office desk, which ranges from 0.70 to 0.85 m, while AOI is usually 0.5 m from the boundary walls and windows (Kruisselbrink, Dangol and Rosemann, 2018).

This Chapter presents an evaluation of the "as-is" daylight performance of the case study building based on the daylighting factors reviewed in Chapters 1 and 2 and the method presented in Chapter 3. Lighting energy consumption and potential energy savings due to the building's "as-is" daylight performance were also analysed. The Chapter starts with the experimental-based daylight illuminance analyses of selected offices in the building and their respective lighting energy performance. Thereafter, the simulated whole-building daylight and energy performance analyses are presented, followed by the derivation of sub-findings to sub-questions 1, what is the status quo (as-is) EUI for the selected case study building? And sub-questions 3, what is the "as-is" contribution of daylighting to the EUI of the building?

4.2 Experimental-based Daylighting Performance Analysis of the Building

The primary objective of the experiment was to derive the "as-is" work plane daylight illuminance of the selected offices (spaces 49, 41 and 43 on the building's ground floor and spaces 11, 15, and 22 on the top floor). The daylight illuminance of the spaces was monitored concurrently with the outdoor ambient solar radiation and horizontal daylight illuminance, as analysed in the next section.

4.2.1 Outdoor ambient solar radiation and light level

For the purposes of this study, global horizontal irradiance (GHI) was prioritised because it consists of both direct normal irradiance and diffuse horizontal irradiance. It is therefore sufficient to illustrate solar radiation availability of outdoor horizontal daylight illuminance (HDI) versus the resultant indoor daylight performance. The measured GHI and HDI are presented in Figure 4.1.

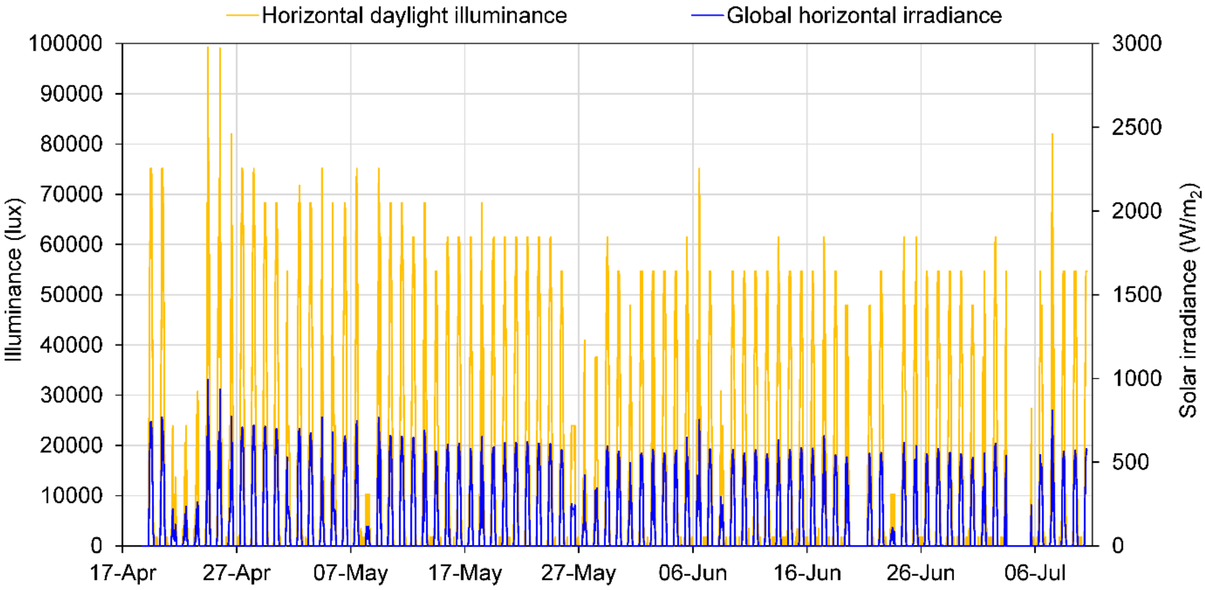


Figure 4.1: Measured global horizontal irradiance and outdoor horizontal daylight illuminance in the monitoring period

From Figure 4.1, April and May's data represent summer GHI and HDI, while winter GHI and HDI were obtained from June and July. In the entire monitoring period, a total of 3 974 data entries were captured for GHI and HDI. However, 184 data entries, approximate 5% of the total data entries, were lost due to the data acquisition system malfunction. The lost data only occurred in the GHI and HDI, while the indoor illuminance data entries were intact. The missing data were excluded in all analyses.

The observed average summer GHI was 353.0 W/m^2, with a peak of 994.0 W/m^2 at 12h00 in April. The resultant HDI was found to be 36 407.24 lux on average, peaking at the same time as GHI at 99 250 lux. The obtained maximum HDI is 750 lux less than a typical clear sky sunlight illuminance, according to Al-Obaidi, Ismail and Abdul Rahman (2015:2). Further, slightly less irradiance and illuminance were observed in the winter period. The average winter GHI and HDI were found to be 331.58 W/m^2 and 33 457.55 lux, respectively. The maximum values recorded for both parameters were 811.0 W/m^2 and 82 000.0 lux at 12h30 in July.

Although the obtained outdoor HDI in the winter season was lesser than a clear sky sunlight illuminance by 18 000 lux, Figure 4.1 indicates adequate solar irradiance and outdoor daylight for effective daylighting in the building, considering that typical workplace light requirement ranges from 100.0 lux to 3 000.0 lux (Szokolay, 2008:192). However, building designs, human factors, and adjacent structures are other influencing factors that must be considered.

Further, the sky conditions used to analyse the indoor daylight performance of the selected offices were deduced from Figure 4.1. This was achieved based on the daily peak GHI and distribution pattern. It was assumed that days with peak GHI greater than or equal to 500.0 W/m^2 and uniform GHI distribution were clear sky days, while days with peak GHI lesser than 500.0 W/m^2 with irregular GHI distribution were cloudy sky days. Based on these assumptions, 19 April and 15 June were considered summer and winter clear sky days, respectively, while summer and winter cloudy sky days were respectively represented by 22 April and 23 June.

4.2.2 Indoor daylight illuminance

The indoor daylight illuminance in this section covers the "as-is" daylight performance of selected offices in the building. In other words, no daylighting interventions were implemented or considered. Also, the daily activities of the occupants in terms of the operation of lights and windows were not constrained. The indoor illuminance of the selected offices in the entire monitoring period is presented in Figure 4.2.

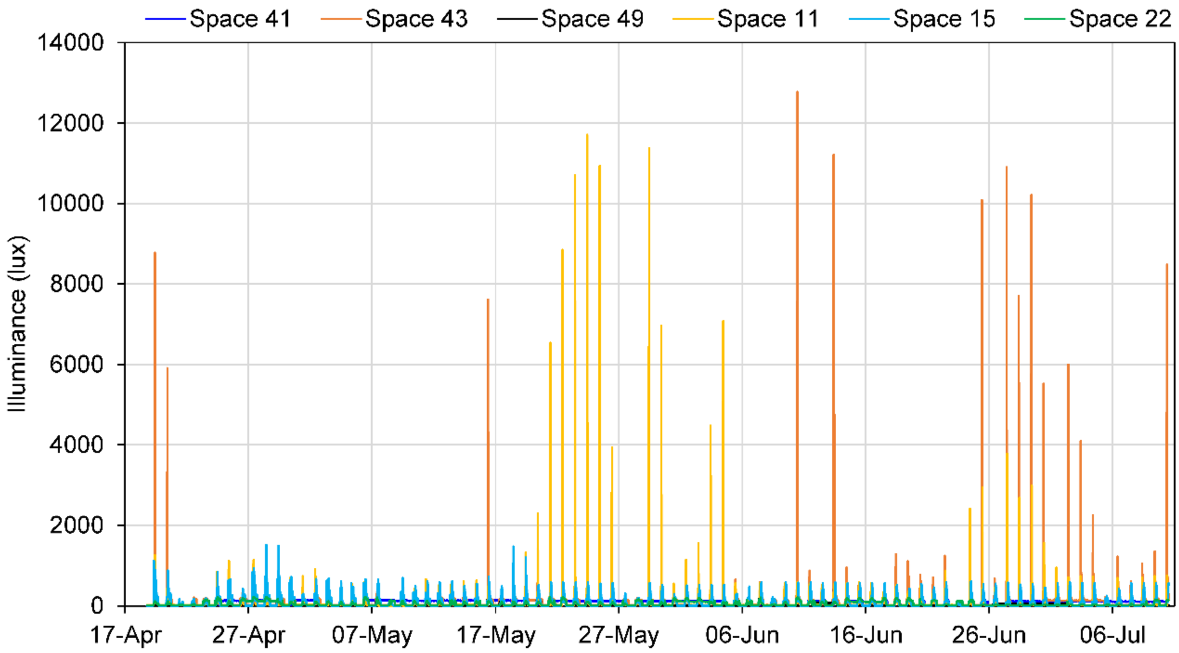


Figure 4.2: Indoor illuminance of selected offices in the case study building

The illuminance in Figure 4.2 is a combination of electric light, daylight, and ambient light. Ambient lights include streetlights, moonlight, and electric light from the hallways. In the presence of the sun (periods with GHI greater than 0 W/m^2), daylight illuminance was found to be dominant in some spaces. At night (absence of the sun, periods with 0 W/m^2 GHI), the ambient lights were dominant when the electric lights were switched off. A synopsis of the lighting performance of the selected spaces is presented in Table 4-1, where an adjusted summer and winter time of the sun's absence and presence was used to accommodate both seasons' data in the same table. From the measured data, summer season sunrise and sunset were 07h00 and 17h30 daily, while sunrise was 07h30 and sunset was 16h30 in winter season. Hence, the time of the sun's absence and presence were adjusted for seasons in Table 4-1.

Table 4-1: Lighting performance of the selected offices in the case study building

Space	Sun absence (18h00 – 6h30)				Sun presence (08h00 – 16h00)			
	Avg. (lux)	Max. (lux)	Min. (lux)	Electric lights on duration (days)	Avg. (lux)	Max. (lux)	Peak time	Actual daylight (lux)
41	72.64	145.80	3.90	47	113.04	208.90	April 12h30	40.40
43	30.84	177.40	19.70	6	261.75	12775.60	June 11h00	230.91
49	13.13	82.80	3.90	8	52.65	413.90	June 11h00	39.52
11	11.42	27.60	3.90	0	208.40	11711.30	May 10h30	208.40
15	0.20	3.00	0.00	0	202.72	1503.00	April 10h30	202.72
22	24.88	130.11	11.18	9	80.86	224.70	April 10h00	55.98

The illuminance in all the spaces besides space 15 was above 0 lux in the absence of the sun. This is attributed to the illuminance of ambient light sources, as indicated earlier. A photo of the top-floor hallway of the building indicating a source of ambient lights is presented in Figure 4.3.

Figure 4.3: Hallway of the selected ground floor selected offices

As shown in Figure 4.3, the upper area, approximately 0.20 m^2, of the doors of most spaces (offices, lecture halls, and laboratories) in the building were made of glass. The glass area of the door allows light from the hallways into the spaces at night and during the day since the lights on the hallways were observed to be switched on constantly. Space 15 had a similar door design as shown in Figure 4.3, but the glass area was covered with cardboard paper to measure the electric light illuminance without the interference of the lights in the hallway, which was found to be 185.0 lux. However, the measured electric lights' illuminance of space 15 cannot be adopted for the other spaces since illuminance is a factor of floor area, the amount of light in a given space, and the position of the sensors with respect to the external windows. This is evident in Table 4-1, where the average and maximum illuminances in the absence of the sun are shown to vary. The actual daylight illuminance of the offices is therefore derived as the difference between the average illuminance in the presence of the sun and average illuminance in the absence of the sun, which would primarily be due to electric lights indoors and in the hallways.

In the presence of the sun, the offices (spaces 11, 15, 41, and 43) on the east side of the building were found to have the highest daylight illuminance. Except for space 41, the average daylight illuminance in the east offices was 224.29 lux and 155.89 lux, excluding potential electric light illuminance. In a similar approach, the average daylight illuminance in space 41 was 40.40 lux, which is five times less than that of the other east offices. Human factors or behaviour is the major cause of the relatively low daylight illuminance observed in space 41. A photo of space 41 inner space is presented in Figure 4.4.

As shown in Figures 3.6 and 3.7, space 41 is the only office with Venetian aluminium blinds. The blinds used in the office prevent a significant amount of sunlight from the inner space, as shown in Figure 4.4. Despite the poor choice of window cover, opening the blinds during the day would allow the penetration of sunlight for effective daylighting. As shown in Figure 4.4, this is not a common practice by the occupants who usually rely on electric lights to illuminate the office space rather than daylighting allowed by opening blinds. It would be interesting to establish the reason for such behaviour based on qualitative approach, but this falls outside the scope of this research.

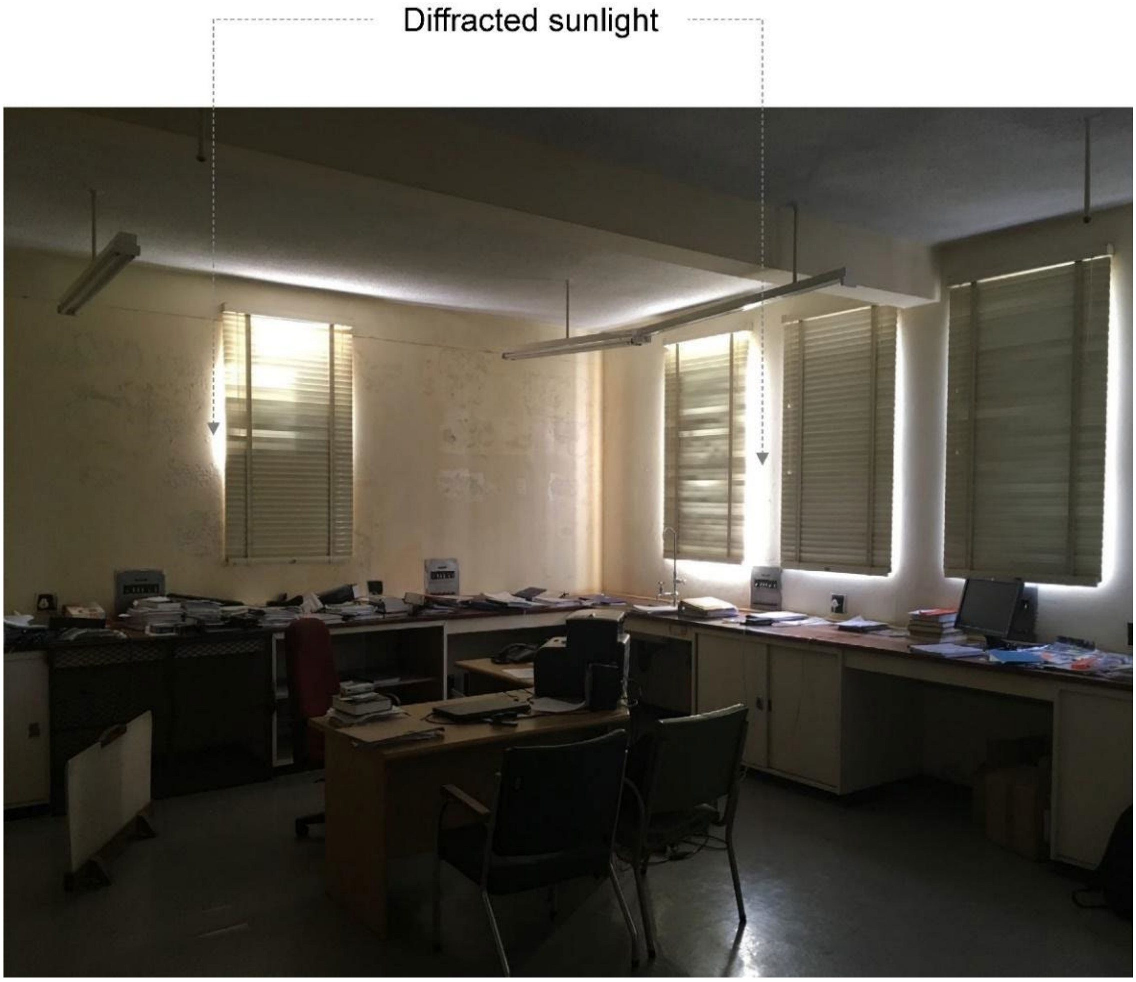


Figure 4.4: A photo of the inner space of space 41

In contrast, daylight illuminance distribution for spaces 43 and 11 was dominant in both seasons (see Figure 4.2). The peak illuminance in both spaces was found to exceed 2 000 lux on several occasions between 9h00 to 11h00. The peaks are in line with the daily trajectory of the sun since the sun angle is lower in the summer and winter seasons during sunrise and sunset. The captured low-angle sun penetration through the windows is shown in Figure 4.5.

From Figure 4.5, the illuminance peaks in spaces 43 and 11 were due to direct sunrays through the blinds as a result of the low sun angle, as explained above. This resulted in a maximum illuminance of 12 775.60 lux and 11 711.30 lux in spaces 43 and 11, respectively, which pose a risk of glare and visual discomfort for the occupants (Kunwar *et al.*, 2020). According to Kunwar *et al.* (2020:5), daylight illuminance above 2 000 lux is likely to cause visual discomfort and glare in direct contact with the human eyes.

Figure 4.5: Sun rays falling on the desk and light sensor in space 11

Offices on the west side of the building were found to have the least daylight illuminance, with an average of 39.52 lux and 58.86 lux in spaces 49 and 22, respectively. Once again, these findings are in line with the daily trajectory of the sun. Spaces on the west side only receive direct sunrays late in the afternoon in the summer season. In the winter season, the spaces are in the shade throughout the day due to the sunset azimuth angle relative to the orientation of the building. In addition, the location of the sensor, i.e., the distance of the office desk from the window, is another contributing factor to the low levels of daylight illuminance observed.

Furthermore, the daylighting in each of the selected offices was analysed in summer and winter with clear and cloudy sky conditions. Based on the sky conditions assumption as discussed in Section 4.2.1, GHI and HDI for typical summer clear and cloudy sky days, as well as the resultant daylight illuminance in the selected offices, are presented in Figure 4.6.

On a typical summer clear sky day, as presented in Figure 4.6 (a), the average GHI between 07h00 and 17h30 was 439.0 W/m^2, peaking at 12h00 at 743.10 W/m^2. In the same period, the corresponding average HDI was found to be 45 021.59 lux and peaking at 75 140.0 lux between 11h00 to 13h00. From Figure 4.6 (c), the average GHI was 85.81 W/m^2 between 07h00 and 17h30, with a maximum of 234.50 W/m^2 at 14h00. The resultant HDI was 9 160 lux average with a peak illuminance of 26 490.0 lux at 11h30. As expected, a significant difference was observed between the clear and cloudy sky GHI.

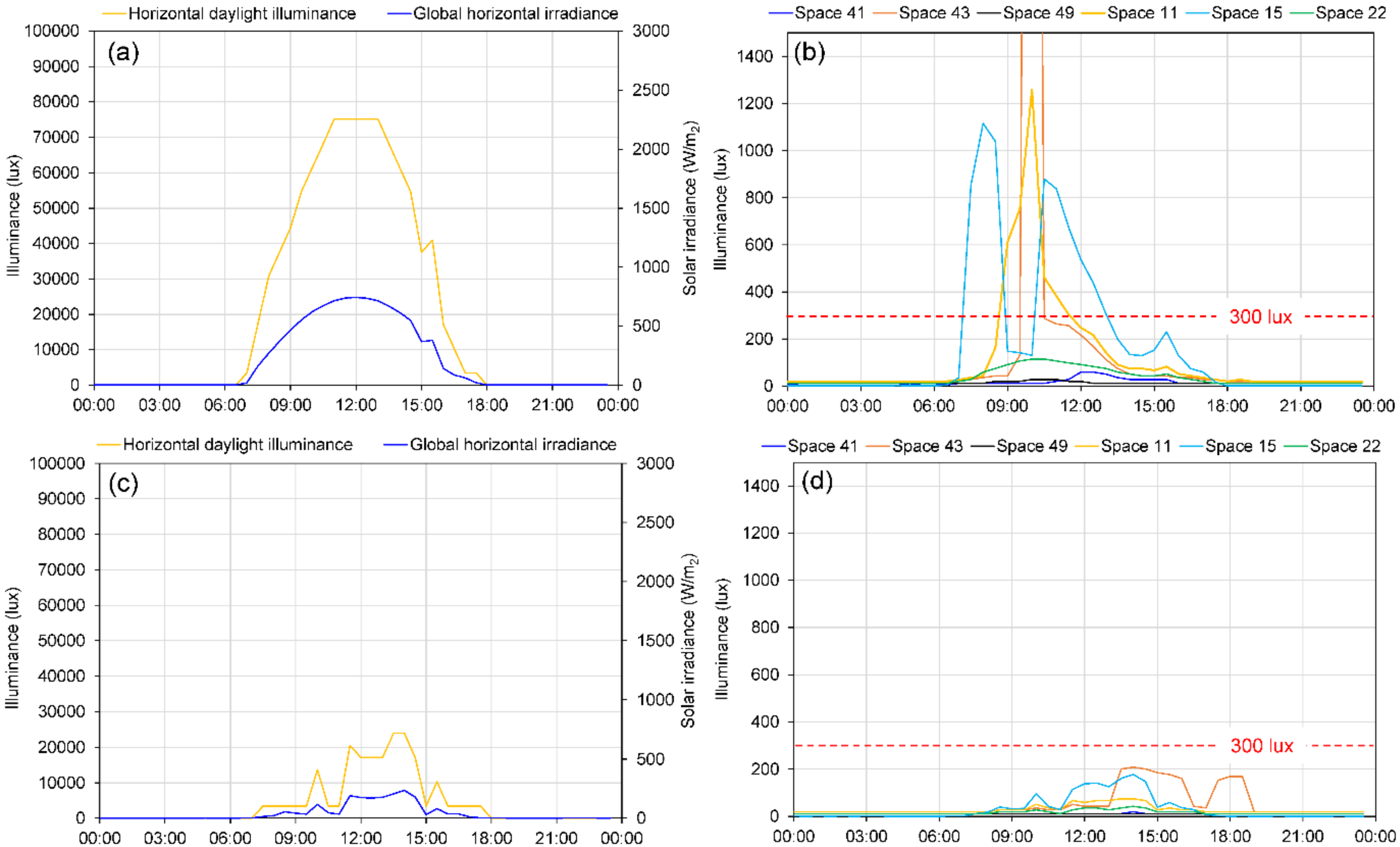


Figure 4.6: Summer season: (a) clear sky day global horizontal irradiance and horizontal daylight illuminance, (b) clear sky day indoor daylight illuminance of selected offices, (c) cloudy sky day global horizontal irradiance and horizontal daylight illuminance, and (d) cloudy sky day indoor daylight illuminance of selected offices

Clear and cloudy sky GHI differences were also observed in the indoor daylight illuminance of the offices. As shown in Figure 4.6 (b), spaces 43, 11, and 15 illuminances exceeded the South African workplace light benchmark of 300 lux. However, this was not the case on the cloudy sky day, where the illuminance of all the offices was below the 300 lux benchmark. A synopsis of the selected offices' illuminance in summer clear and cloudy sky days are presented in Table 4-2, where the actual daylight illuminance of the selected offices was below 100 lux on a typical cloudy sky day. In contrast, the actual daylight illuminance in spaces 43, 11 and 15 was above 100 lux on a clear sky day. Although there was no indication of daytime use of electric lights in Figures 4.6 (b) and (c) during the sun's absence, potential external (hallway) illuminance was also taken into consideration in the actual daylight illuminance in spaces 41, 43, 49 and 22.

Further, the sun absence and presence times in Table 4-2 are based on the sun absence and presence assumptions given in Figure 4.2. The sun absence and presence times in Table 4-2 are slightly different from Table 4-1 because Table 4-1 is based on the entire monitoring period, while Table 4-2 focuses on summer season only.

Table 4-2: Typical clear and cloudy sky illuminance levels of the selected offices in the summer season

Clear sky day							
space	**Sun absence (18h00 – 06h00)**			**Sun presence (07h00 – 17h30)**			
	Avg. (lux)	**Max. (lux)**	**Min. (lux)**	**Avg. (lux)**	**Max. (lux)**	**Peak time**	**Actual daylight (lux)**
41	10.89	11.80	3.90	22.92	59.10	11h00	12.03
43	19.70	19.70	19.70	489.52	8770.70	10h00	469.82
49	11.80	11.80	11.80	15.75	27.60	10h00	3.95
11	19.70	19.70	19.70	236.16	1257.50	10h00	236.16
15	0	0	0	375.95	1115.0	08h00	375.95
22	11.80	11.80	11.80	63.78	114.30	10h00	51.98
Cloudy sky day							
space	**Sun absence (18h00 – 06h00)**			**Sun presence (07h00 – 17h30)**			
	Avg. (lux)	**Max. (lux)**	**Min.**	**Avg. (lux)**	**Max. (lux)**	**Peak time**	**Actual daylight (lux)**
41	11.80	11.80	11.80	11.8	19.70	14h00	0
43	19.70	19.70	19.70	80.99	208.90	14h00	61.29
49	11.80	11.80	11.80	11.80	11.80	-	0
11	19.70	19.70	19.70	40.49	74.9	14h00	20.79
15	0	0	0	67.55	178.0	14h00	67.55
22	11.80	11.80	11.80	22.57	43.4	14h00	10.77

From Figure 4.7, relatively low GHI and HDI on the cloudy sky day resulted in a similar poor indoor daylight illuminance in all the offices, especially in the winter season. Between 07h30 to 17h00, the average cloudy sky day GHI was 47.74 W/m^2 with a maximum of 110.6 W/m^2 at 11h30. The average HDI was 4 953.0 lux with a maximum of 10 250 lux, peaking several times of the day. In Figures 4.7 (b) and (d), space 41 and 22 illuminance were unusually higher than their respective sun absence average illuminances of 10.89 lux and 11.8 lux on a clear sky day, as shown in Table 4-2. This implies the use of electric lights in the absence and presence of the sun. On the clear sky day, the electric lights in space 41 were switched on for 18.5 hours, between 00h00 and 18h00, while in space 22, the lights were on for 24 hours. On the cloudy sky day, the electric lights in space 41 were observed to be on for 3.5 hours, from 16h00 to 19h00 and 11 hours, between 16h00 and 19h00 in space 22. Table 4-3 presents a synopsis of typical winter clear and cloudy sky days illuminance of the selected offices.

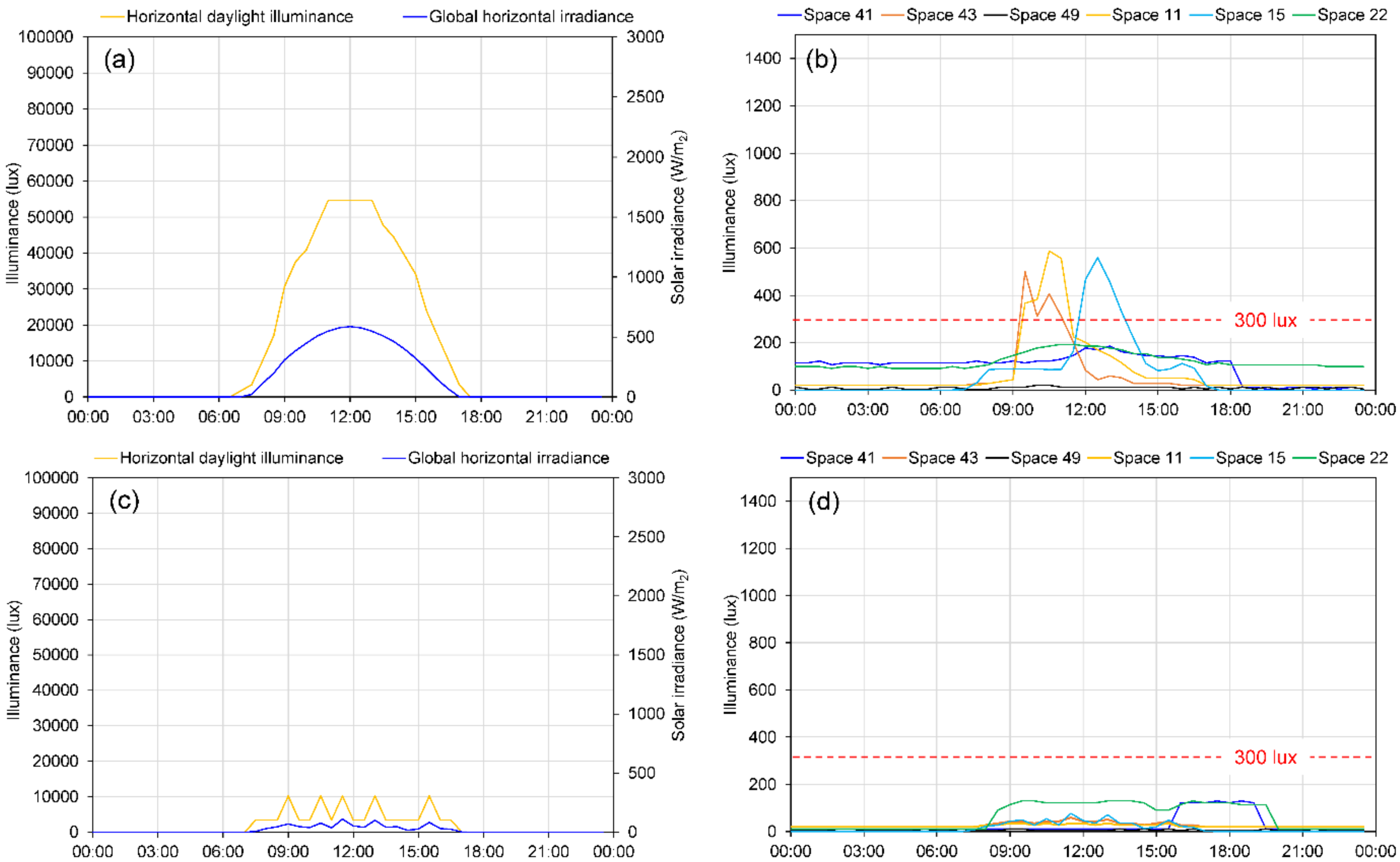


Figure 4.7: Winter season: (a) clear sky day global horizontal irradiance and horizontal daylight illuminance, (b) clear sky day indoor daylight illuminance of selected offices, (c) cloudy sky day global horizontal irradiance and horizontal daylight illuminance, and (d) cloudy sky day indoor daylight illuminance of selected offices

Table 4-3: Typical clear and cloudy illuminance of the selected office in the winter season

Clear sky day							
Space	Sun absence (17h30 – 06h30)			Sun presence (07h00 – 17h00)			
	Avg. (lux)	Max. (lux)	Min.	Avg. (lux)	Max. (lux)	Peak time	Avg. (lux)
41	71.37	122.20	3.90	137.96	185.3	13h00	66.59
43	19.70	19.70	19.70	109.06	500.60	9h30	89.36
49	7.41	11.80	11.80	10.67	19.70	10h00	3.26
11	19.70	19.70	19.70	154.41	587.30	10h30	154.41
15	0	0	0	159.28	560.0	12h30	159.28
22	99.40	114.3	90.70	149.61	193.20	11h00	50.21
Cloudy sky day							
Space	Sun absence (17h30 – 06h30)			Sun presence (07h00 – 17h00)			
	Avg. (lux)	Max. (lux)	Min.	Avg. (lux)	Max. (lux)	Peak time	Avg. (lux)
41	28.14	130.10	11.80	28.36	122.20	17h00	0
43	19.70	19.70	19.70	37.07	59.10	11h00	37.07
49	5.59	11.8	3.90	6.27	11.80	15h00	6.27
11	19.7	19.70	19.70	28.79	35.50	10h00	28.79
15	0	0	0	34.55	77.0	11h30	34.55
22	30.67	122.20	11.80	108.02	130.10	14h30	77.35

The average actual daylight illuminance of all offices on a cloudy sky day was below 100 lux, and only spaces 11 and 15 daylight illuminances were above 100 lux on a typical winter clear sky day. The number of hours when daylight illuminance was above the 300 lux benchmark was used to determine the daylight performance of the selected offices. In other words, based on an on/off approach for electric lights, offices with illuminance greater than 300 lux in the presence of the sun can sufficiently utilise daylight for office tasks without the need for electric lights. A similar principle was adopted by Lim *et al.* (2017) to determine the automated on/off daylight-linked energy savings in a green design office building in Malaysia. The automated on/off daylight-linked principle was used in this experiment to determine the potential daylight energy savings of the selected offices.

4.2.3 As-is daylighting energy performance and potential

Although daylight-linked sensors were not installed in the selected offices, the automated on/off daylight-linked principle of operation was used to derive the experimental "as-is" daylight energy performance of the offices. As indicated in Chapter 2, the on/off daylight-linked principle is based on the automated operation of electric lights using pre-set illuminance. The electric lights are automatically switched off by the daylight-linked sensor when indoor illuminance is equal to or above the pre-set illuminance and on when the illuminance is below (Lim *et al.*, 2017). The selected offices' light energy consumption and potential daylight energy savings were computed using Equation (1) and appendix A-1 and A-2. Figure 4.8 shows typical summer clear sky lighting and daylight-linked energy performances for the selected offices.

In Figure 4.8, the baseline represents the “as-is” lighting profile of the selected offices without the use of a daylight-linked sensor, while daylight-linked is the lighting profile based on the principle of on/off daylight-linked operation. Considering that the illuminances of all the offices were below the 300 lux benchmark on cloudy sky days (see Figures 4.6 and 4.7), their lighting energy is equal to the baseline light energy in Figure 4.8. This is also applicable to space 22, while space 49 has a distinctive profile that will be covered later in this section.

From appendix A-1 and A-2, the total lights wattage of the selected offices can be grouped into 420 W, and 140 W. Spaces 41 and 49 have a total lights-wattage of 420 W each, while spaces 43, 11, 15, and 22 have 140 W each.

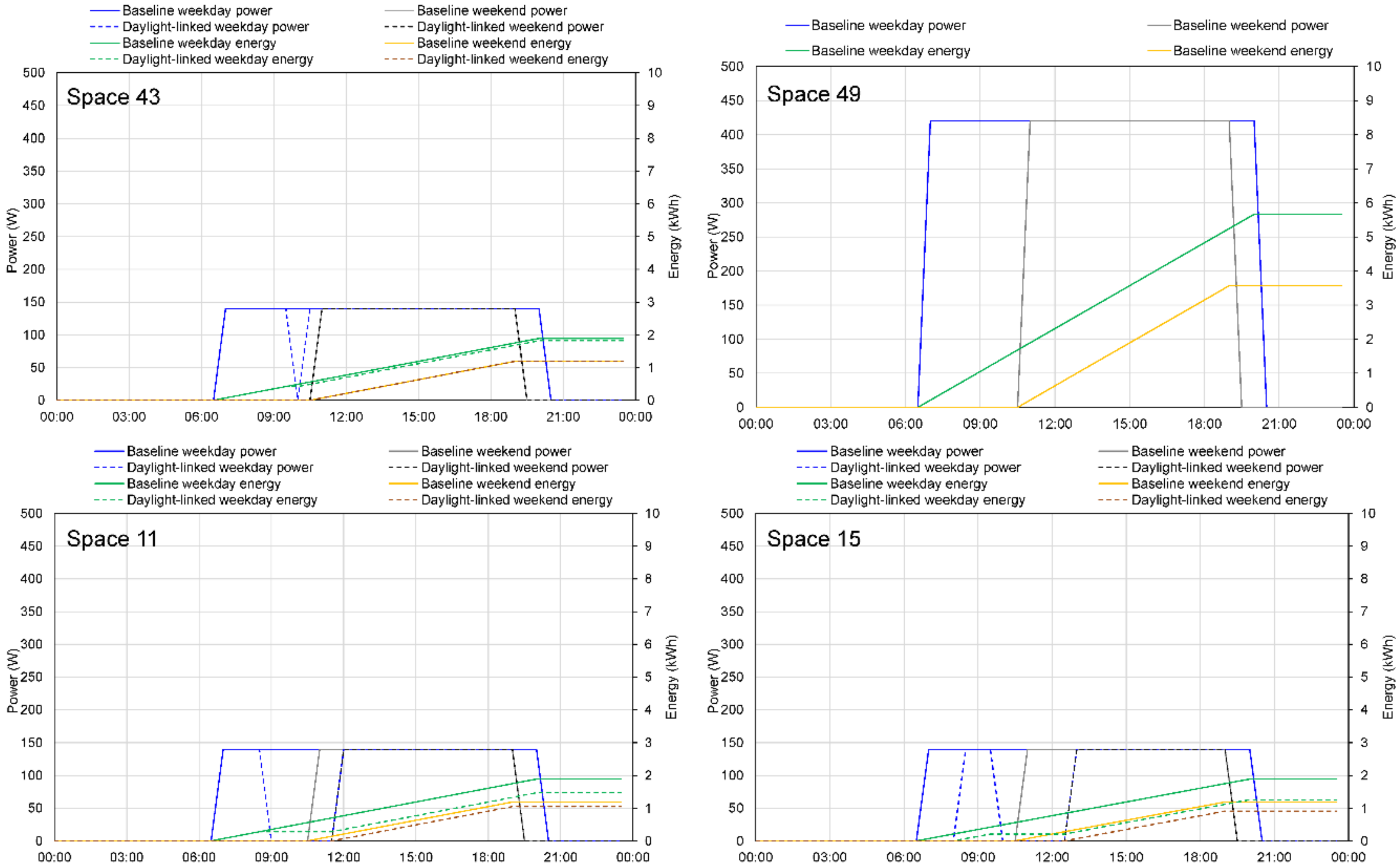


Figure 4.8: Typical summer season clear sky daylight energy consumption and daylight energy savings

In terms of burning hours, 08h00 to 17h00 is the weekday time frame for classes and laboratory activities, according to the University of Fort Hare Faculty of Science and Agriculture 2018 prospectus. However, the measured indoor illuminance of the selected offices (see Figure 4.2 and Table 4-1) shows activities in some of the offices beyond the above-mentioned time frame. It was observed that space 41 electric lights were switched on 57% (47 days) of the entire monitoring period. Space 22 had the second-highest duration of electric lights usage outside the working hours with 11% (9 days). Considering the Faculty time frame and measured indoor illuminance, the following assumptions were made to establish burning hours of electric lights in the selected offices.

- All electric lights in a given space were operated by a control switch and were switched on whenever space was occupied.
- The electric lights in space 41 were switched on 24 hours of the weekdays and weekends.
- The electric lights in spaces 43, 49, 11, 15, and 22 were switched on between 08h00 and 20h00 on weekdays and switched on from 10h00 to 19h00 on weekends.
- The lighting operation pattern is the same in the summer and winter seasons.

A summary of the lighting energy performance of the selected offices is presented in Table 4-4.

Table 4-4: Summer clear sky day lighting energy performance of the selected offices

Space	Baseline			Daylight-linked				
	Demand (W)	Energy (kWh/day)		Daylight period (h)	Energy (kWh/day)		Saving (%)	
		Wkday	Wkend		Wkday	Wkend	Wkday	Wkend
41	420	10.08	10.08	0	0	0	0	0
43	140	1.89	1.19	0.5	1.82	1.19	4	0
49	420	5.67	3.57	0	0	0	0	0
11	140	1.89	1.19	3.0	1.47	1.05	22	12
15	140	1.89	1.19	4.5	1.26	0.91	33	24
22	140	1.89	1.19	0	0	0	0	0

As indicated in Table 4-4, space 41 had the highest lighting energy consumption due to its total light-wattage and assumed lights burning hours. In contrast, space 15 was found to have the most daylight-linked energy saving potential, with 33% and 24% on weekdays and weekends, respectively. Typical winter clear sky day lighting energy performance was similarly computed using Equation (1) and Appendix A-1 and A-2 and presented in Figure 4.9.

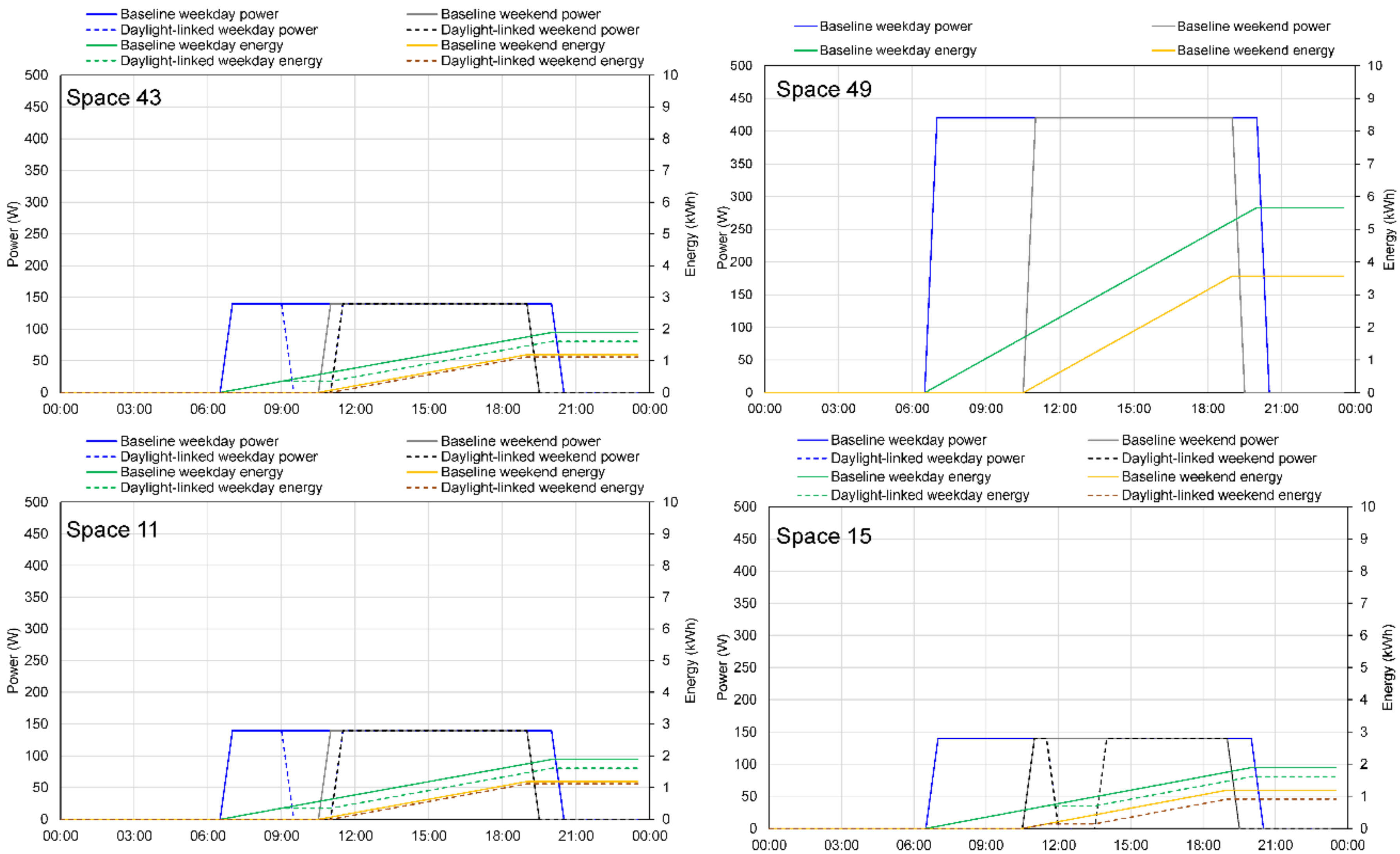


Figure 4.9: Typical winter clear sky day lights energy consumption and daylight energy savings

Similar approaches and assumptions were adopted in computing the winter clear sky day lighting energy of the selected offices. The baseline energy was the same, with an average of 10.08 kWh/day for space 41, 1.69 kWh/day for spaces 43, 11, 15, and 22, and 5.58 kWh/day for space 49. Space 41 was still the most underperforming, with the highest lighting energy consumption and no daylight-linked energy saving potential. The daylight-linked energy consumption for spaces 43, 11, and 15 was 1.61 kWh/day each on weekdays, saving 15%. On weekends, the daylight-linked energy consumption for spaces 43 and 11 was 1.12 kWh/day with 41% savings, while 0.91 kWh/day was obtained in space 15, thus amounting to 52% energy savings. Further, the energy charges of the MEGA FLEX tariff structure used in computing the selected spaces lighting energy costs are presented in Table 4-5 (Eskom, 2021).

Table 4-5: MEGA FLEX Nightsave Urban Small tariff energy charges (Eskom, 2021)

Transmission Zone	**Voltage**	**High demand season (Jun-Aug) VAT incl.(c/kWh)**			**Low demand season (Sep-May) VAT incl. (c/kWh)**		
		Peak	**Standard**	**Off-peak**	**Peak**	**Standard**	**Off-peak**
≤ 300 km	< 500 V	479.96	146.03	79.74	157.17	108.45	69.14
	≥ 500 V & < 66 kV	472.43	143.12	77.73	154.09	106.08	67.3
	≥ 66 kV & ≤ 132 kV	457.47	138.58	75.27	149.25	102.7	65.18
	≥ 132 kV	431.15	130.59	70.93	140.68	96.8	61.42

From Table 4-5, the MEGA FLEX energy charges vary with season. June to August, which is considered the winter (high demand) season, has the highest energy charges, while September to May represents the summer (low demand) season and has the least energy charges. The energy charges are further classified according to time of use (TOU). The TOU include peak, which consists of the morning peak, 07h00 to 09h30 and the evening peak, 18h00 to 19h30. Also, the standard TOU is made up of morning standard, 6h00 to 6h30, midday standard, 10h00 to 17h30, and evening standard, 20h00 to 21h30. Lastly, the off-peak TOU includes morning off-peak, 0h00 to 5h30 and evening off-peak, 22h00 to 23h30. It is worth noting that the tariff time frames are given in 30 minutes intervals, so a minute after a given time frame, the nearest tariff applies. Further, the least transmission zone was adopted in the research since the nearest sub-station is 100 km away from the University. Considering the above energy-charge factors, Equation (2) and Figure 4.8 combined with Table 4-5 were used to deduce the typical summer clear sky day operational lighting energy cost of the selected offices, which are presented in Figure 4.10.

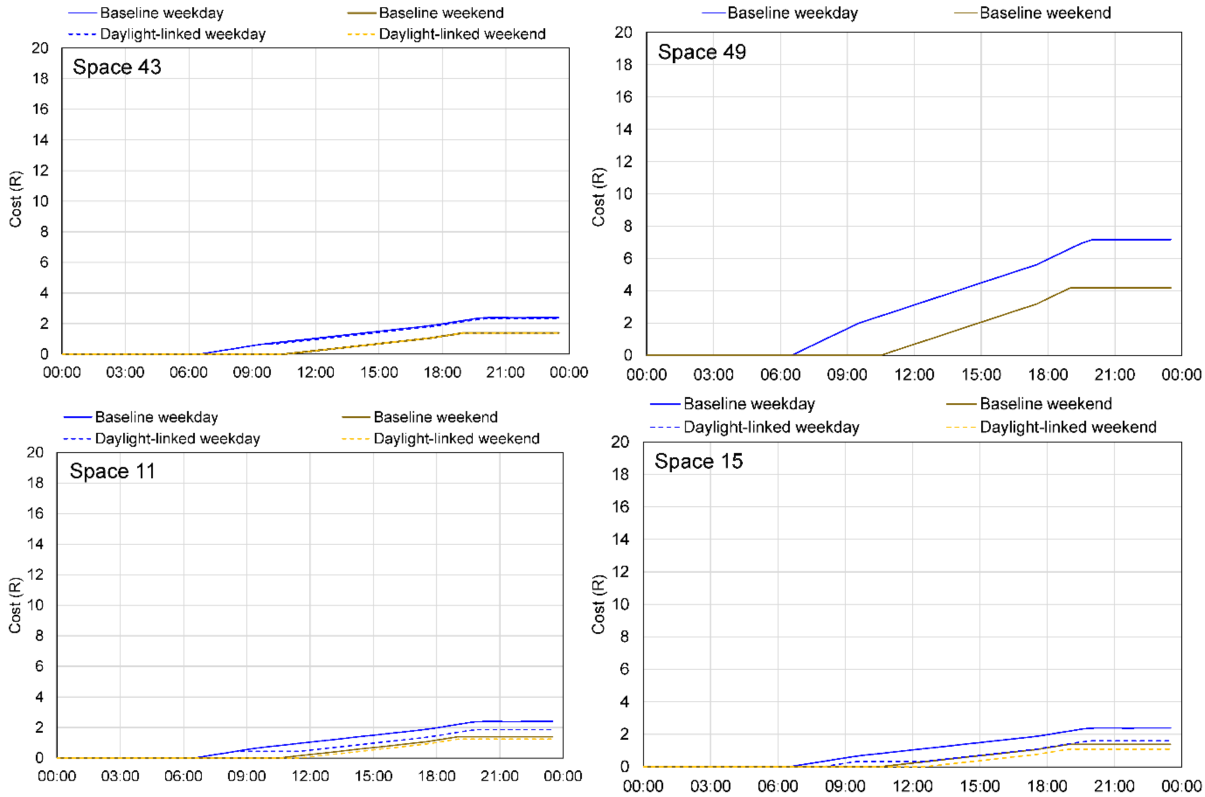


Figure 4.10: Summer season clear sky day light energy cost of the selected offices

The low demand energy charges were adopted in computing summer clear sky day lighting energy cost given in Figure 4.10. The data indicate that Space 41 incurred the highest lighting energy cost, with an average of R2.5 per hour, amounting to a daily cumulative cost of R10.63. The daily cumulative lighting energy cost for spaces 43, 11, 15, and 22 was R 2.37 on weekdays and R1.39 on weekends, while space 49 lighting energy cost amounted to R7.17/day on weekdays and R4.18/day on weekends. However, spaces 43, 11, and 15 have the potential to utilise daylight to reduce their respective lighting energy cost by 4%, 34%, and 57% per week. Similarly, Equation (2) and Figure 4.9, together with Table 4-5, were used to derive the lighting energy cost of the selected offices on a typical winter clear sky day, as presented in Figure 4.11.

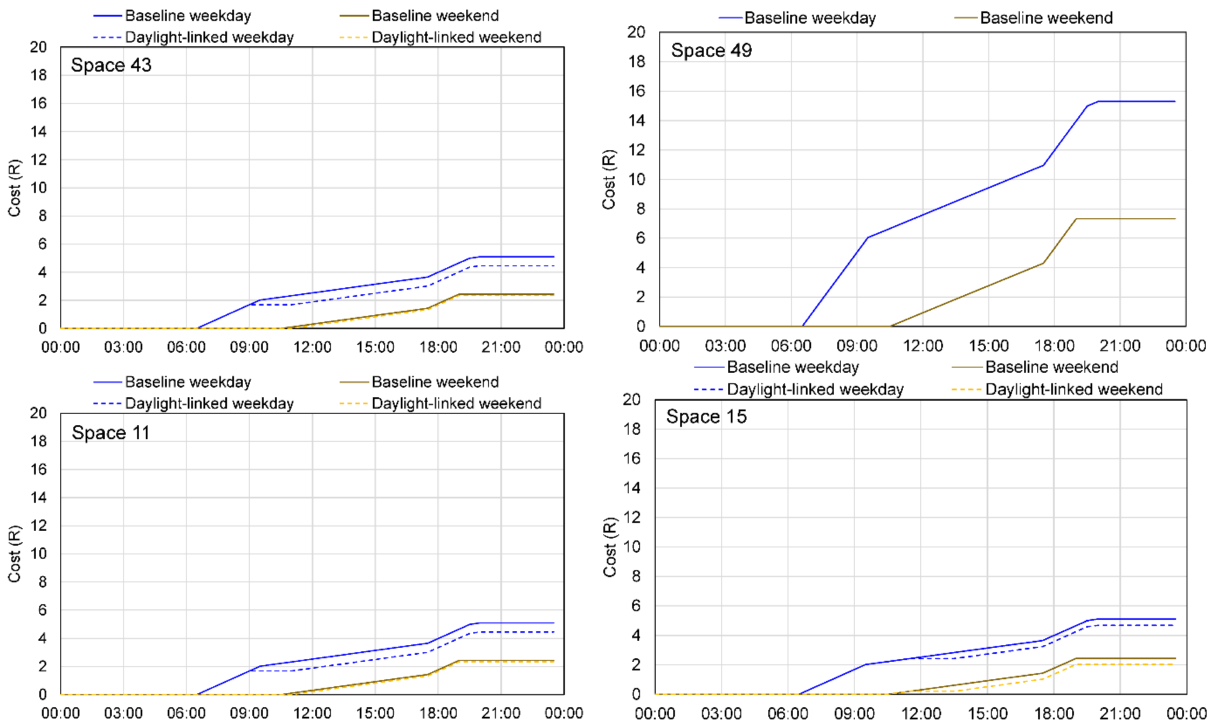


Figure 4.11: Winter season clear sky day light energy cost of the selected offices

As expected, the winter season lighting energy cost was higher by approximately 50% due to the high demand (winter) charges. The average daily cumulative lighting energy cost for space 41 was R 19.51, while space 49 had a total daily lighting energy cost of R 15.29 on weekdays and R 7.32 on weekends. The baseline lighting energy cost for spaces 43, 11, 15 and 22 was R 5.10 and R 2.44 on weekdays and weekends, respectively. The lighting energy cost savings were 17% per week in spaces 43 and 11, as well as in space 15 by 25% per week.

4.3 Conclusions

This Chapter presents data, analyses and sub-findings on the experimental and simulation "as-is" daylighting and energy performance of the case study building. The impact of the global horizontal irradiance (GHI) and horizontal daylight illuminance (HDI) was demonstrated through the experimental-based evaluation of the building. Cloudy sky days in summer and winter seasons showed the least GHI and HDI, which correlated with poor indoor illuminance below the benchmark of 300 lux at the workplace level. In addition, building orientation relative to the daily traverse of the sun also influenced effective daylighting indoors such that offices on the west side of the building had the least daylight illuminance on typical summer and winter clear sky days, with their average illuminance below 100 lux. On the other hand, the average illuminance in the east-facing offices was up to 469.82 lux, with the maximum daylight illuminance observed in the winter season. Effective daylighting and daylight-linked energy-saving potential of the offices were evaluated against the daylight illuminance versus the South African workplace benchmark of 300 lux. The evaluation shows that only three out of the six offices sampled had effective daylight and hence a potential to utilise daylight-linked control for energy savings.

CHAPTER 5

Simulation and Optimisation of the Building Daylight and Lighting Energy Performances

5.1 Introduction

Data and analyses in the previous Chapter indicate that electric lighting was the second-highest energy consumer, mainly due to the high number of lights in the building and the absence of automated control. All the lights were scheduled to operate whenever a given space was occupied, regardless of the indoor daylight illuminance per the common practice in commercial buildings (Escrivá-Escrivá, 2011). However, daylight-linked sensors based on ambient light levels can be used to aid the operation of lights to minimise energy consumption (Alrubaih *et al.*, 2013). According to Atif and Galasiu (2003), the common operations of daylight-linked sensors are automated on/off and continuous dimming. Irrespective of the operation, daylight-linked sensors are usually installed at the ceiling facing downward (Lim *et al.*, 2017). Other lighting interventions include occupancy-linked and time-based light sensors. The operating principle of occupancy-linked sensors was covered in Chapter 2 (see Section 2.3.1), but it was not considered in the simulation for building lighting energy optimisation.

This Chapter covers daylight interventions for the building lighting and energy performance optimisation and reduction of the overall energy use intensity (EUI) as well as economic and environmental impacts. To this effect, daylight-linked sensors, as explained above, were adopted in the simulation for building energy optimisation. The building daylight distribution and performance analysis based on indoor luminance and illuminance of various spaces in the building was used to kick-start the Chapter.

5.2 Simulation-based Analysis of Daylighting and Energy Performance Analysis of the Building

The experimental section covers the daylight and lighting energy performance of the building with respect to selected offices under normal operating conditions. The effect of the blinds and the operation of the electric lights on the illuminance of the selected offices were demonstrated. In contrast, the simulation-based analysis covers the “as-is” daylighting and whole-building energy performance. The simulation daylight evaluation of the building is mostly based on design conditions. In other words, the effect of the blinds and electric lights were not considered in the simulation. Further, the building daylighting and energy simulation was guided by the local sun path and solar radiation analysis of the building, as covered in the next section.

5.2.1 Sun path and solar distribution for the building

As indicated in Section 4.2, the seasonal daily trajectory and altitude of the sun are critical factors of effective daylighting in a building. A sun path diagram was therefore generated from satellite-based weather data (see Figure 5.1) and applied to evaluate the seasonal daily traverse of the sun relative to the building.

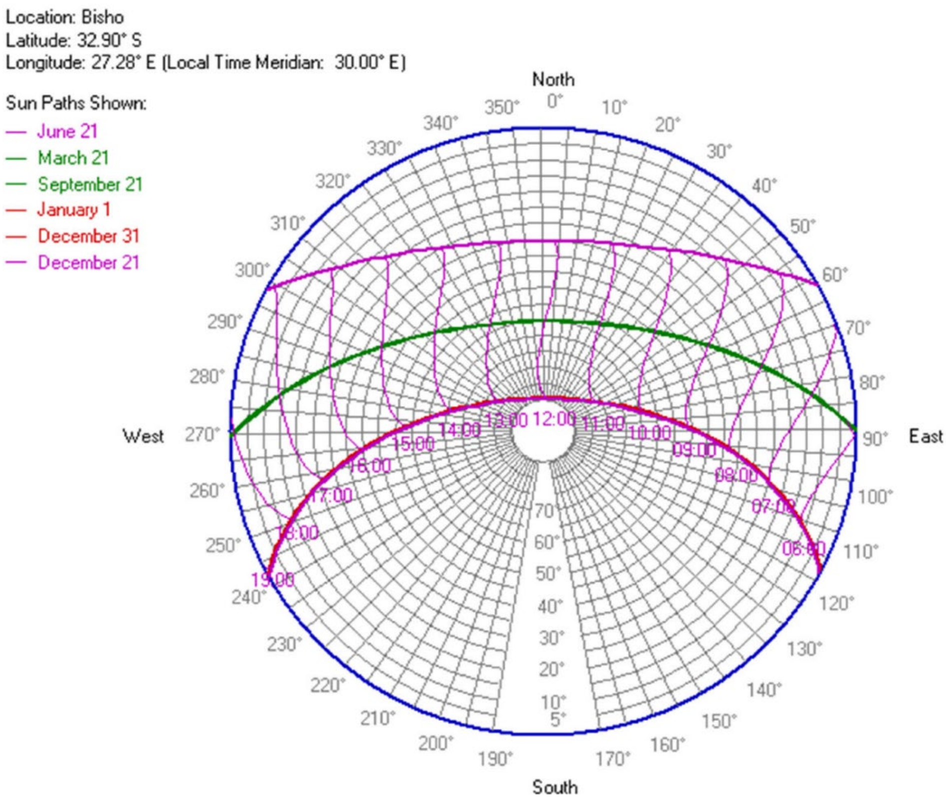


Figure 5.1: Sun path diagram for the latitude of the building

As highlighted in Section 3.3.2, the nearest available local weather data for the building in the IESVE database was from Bisho town. In Figure 5.1, 21 June and 21 December are respectively winter and summer solstice, 21 March and 21 September are the equinoxes, while 01 January to 31 December was selected for annual simulation of the sun path. During the summer solstice, the sun rises at 05h00 due south-east (118.28°), peaks at 12h00 at an altitude of 80.0° and sets at 19h00 due south-west (241.70°). A shorter daytime was observed in the winter solstice as the sun rises at 07h00 due north-east (61.70°) and sets at 17h00 due north-west (298.28°). Hence, the building winter season daylight time is approximately 4 hours shorter. In addition, the sun rises and sets approximately due east (90°) and west (270°) at

06h00 and 18h00, respectively, in the equinox. A synopsis of the annual sun altitude at different times of the month is given in Table 5-1.

Besides the sun azimuth, solar altitude is another important parameter in terms of the penetration of the sun rays into a building. Theoretically, the roof overhang or eaves prevents the summer high altitude sun rays from penetrating through the windows into the building while the winter low altitude sun rays can penetrate deeper (Overen, Meyer and Makaka, 2019). The solar altitude angles in Table 5-1 were simulated using the 15th of each month as the design day (typical day). September to May is also considered the summer season, while June to August is the winter season. The average summer sun altitude was 36.82° with a peak of 80.31 in December, while an average altitude of 23.34° was observed in winter with a peak of 43.18° in August (as one approaches the summer period). The average seasonal sun altitude corresponded with Overen *et al.*'s (2019) findings and justified the difference in seasonal solar penetration angles in the building as shown in Figure 2.2.

A solar shading analysis of the building was conducted, and the findings are presented in Appendix B-1 and B-2. In the solar shading tables, the dark grey sections indicate the times the sun is below the horizon, while the values in the shaded-blue and shaded-yellow are the percentage area of the floor or wall of a particular space that is receiving solar radiation at a given time of the month. The shaded-blue tables contain values for the floor, while the wall's values are given in the shaded-yellow tables. The floor readings indicate internal solar radiation due to penetration of the sun rays, while the wall readings were due to external solar radiation falling on the outer surface of the walls. As shown in Appendix B-1 and B-2, the percentage area of floor and walls receiving solar radiation varies with time, orientation, and season. A virtual illustration of the solar exposure of the building in four different orientations on a typical summer day is presented in Figure 5.2.

In Figure 5.2. the surface of the entire building was divided into a 10 m^2 imaginary grid for the hourly solar exposure analysis. A scale of 0 to 12 hours was selected to accommodate the summer and winter seasons on one scale. From Figure 5.2, only the roof was found to have solar exposure of 12 hours and above. This is followed by the top floor north-facing walls (spaces 14, 16, and 18) with approximately 8 hours of solar exposure. The west-facing walls of space 39 (ground floor) and some portion of space 23 (top floor) were observed to have no solar exposure throughout the day. As indicated in Figures 3.2 and 3.11, the poor solar exposure of the above-mentioned walls is due to the orientation of the building and trees. As shown in the south-east orientation in Figure 5.2, the shading effect of adjacent buildings was observed on the ground floor walls of spaces 41, 42, and 43.

Table 5-1: Annual solar altitude of the building

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						7.37	19.41	31.82	44.39	56.89	68.76	77.54	75.40	65.02	52.83	40.26	27.72	15.42	3.54					
Feb						1.97	14.33	26.90	39.43	51.53	62.36	69.55	68.87	60.87	49.75	37.54	25.00	12.44	0.13					
Mar							9.81	22.29	34.35	45.44	54.50	59.54	58.54	51.97	42.10	30.62	18.39	5.84						
Apr							4.97	16.87	27.90	37.42	44.43	47.61	46.12	40.37	31.64	21.08	9.44							
May							0.39	11.59	21.68	30.05	35.88	38.29	36.79	31.70	23.85	14.11	3.13							
Jun								7.92	17.65	25.68	31.29	33.73	32.59	28.08	20.86	11.69	1.18							
Jul								8.14	18.18	26.58	32.60	35.44	34.60	30.24	23.04	13.83	3.25							
Aug							1.70	13.37	24.10	33.27	40.00	43.18	42.09	37.01	28.92	18.88	7.62							
Sep							10.23	22.45	33.96	44.09	51.65	54.86	52.57	45.64	35.84	24.51	12.38							
Oct						6.04	18.60	31.14	43.34	54.57	63.37	66.68	62.41	53.13	41.72	29.45	16.89	4.35						
Nov						11.04	23.35	35.89	48.45	60.65	71.38	76.22	70.18	59.13	46.84	34.27	21.75	9.48						
Dec						11.04	23.06	35.45	48.01	60.53	72.43	80.31	74.93	63.42	50.97	38.39	25.94	13.82	2.21					

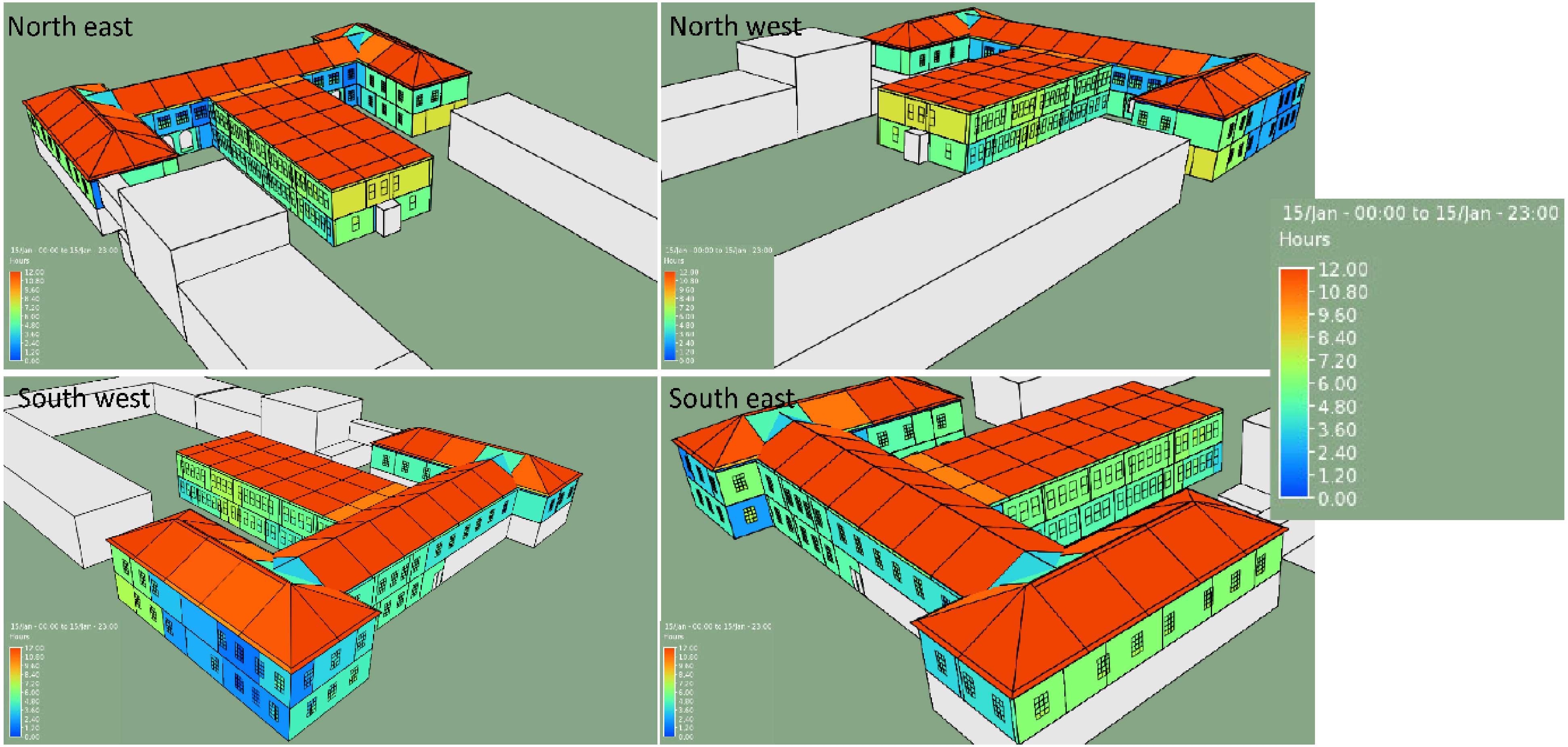


Figure 5.2: Simulated hourly solar exposure of the building on a typical summer day

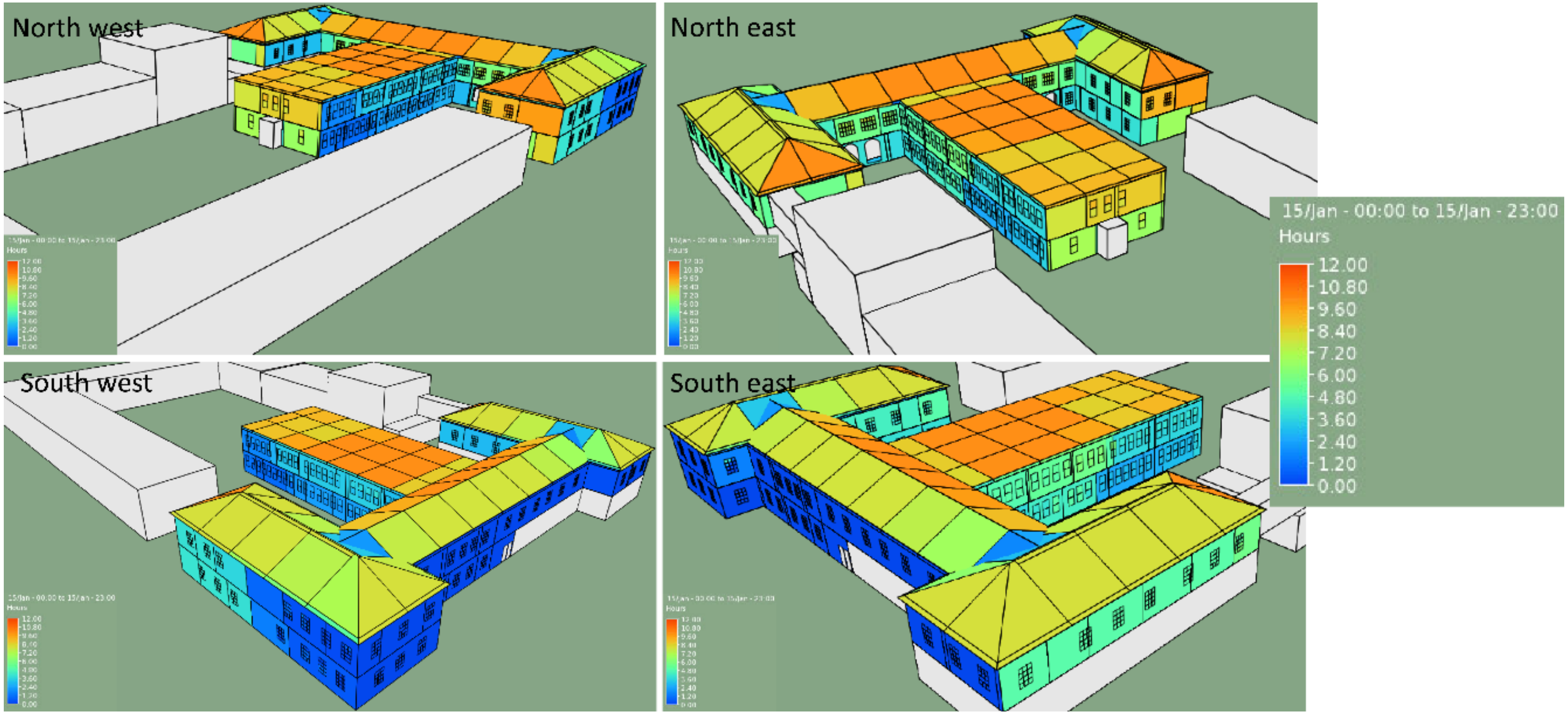


Figure 5.3: Simulated hourly solar exposure of the building on a typical winter day

On the north-west elevation, space 49 walls were found to be affected by the adjacent building and trees, while self-shading resulted in the relatively low solar exposure of walls for space 46. Figure 5.3 presents the hourly solar exposure of the building on a typical winter day.

The maximum solar exposure in Figure 5.3 was approximately 10 hours. The south-facing walls were completely in the shade with zero-hours of solar exposure throughout the day. Spaces 41, 42, and 43 solar exposure hours were found to drop from approximately 6 hours in summer to 2 hours in winter. The west walls, specifically the ground floor, experienced a similar decrease in solar exposure hours. As explained earlier, the relatively low solar exposure hours observed in the winter season are a result of the short winter sun hours. The angles of sunrise and sunset relative to the building orientation and the adjacent structure on the east and west side of the building also contributed to the relatively low solar exposure hours. As discussed further in the next section, the solar exposure hours of the walls are equivalent to the solar exposure of the respective windows on the walls, and this influences the available daylight in the spaces.

5.2.2 Daylight distribution and performance of the building

Given that the building solar exposure hours covered in the previous section do not represent the ambient or indoor light levels, luminance and illuminance were used in this section to analyse the ambient and indoor daylight levels relative to the building orientation and adjacent structures. Figure 5.4 therefore shows the building luminance for various orientations on typical summer and winter days.

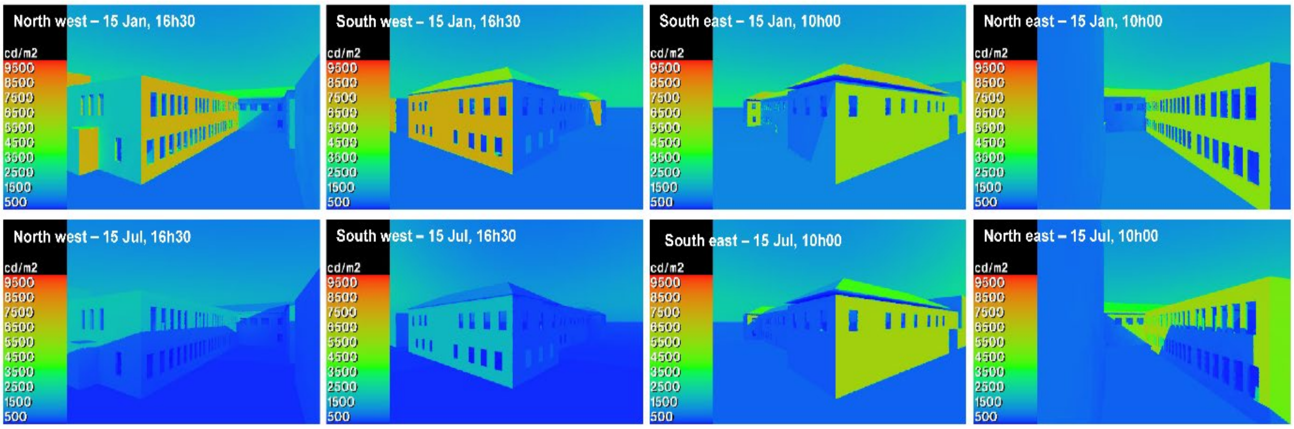


Figure 5.4: Simulated typical summer and winter days outdoor ambient luminance for various orientations

Luminance is simply the brightness of light in a given space or area, thus, Figure 5.4 illustrates the brightness of sunlight on the building walls. The windows were not considered since the majority of sunlight falling on the window (glass) is transmitted into the building. However, it can be assumed that the amount of sunlight falling on the walls is equivalent to the amount falling on windows located on that wall. In Figure 5.4, the impact of the adjacent structure on the building was evident in the winter season at the north-west and north-east elevations. In both elevations, the adjacent building was shading more than half of the west and east-facing walls. The average luminance of the east-facing wall portion in the shade was 350 cd/m^{2,} while the non-shaded portion was 5 700 cd/m^2. The average luminance of the east wall in summer was 5 500 cd/m^2. On the west-facing walls, shading due to the adjacent structure reduces the average luminance from 1 600 cd/m^2 to 240 cd/m^2. However, the average wall luminance was 7 400 cd/m^2.

The luminance of the south-west and south-east walls is a factor of seasonal time of sunrise and sunset relative to the building orientation. Nonetheless, the average luminance of 5 600 cd/m^2 in summer and 6 500 cd/m^2 in winter was observed on the south-east facing walls. The south-facing walls were found to be partially shaded in summer, resulting in an average luminance of 1 500 cd/m^2. In winter, the south-facing walls were completely shaded with an average luminance of 500 cd/m^2. For comparison purposes, sunlight on a sandy beach with direct contact with the human eyes is 28 600 cd/m^2, while a 40 W bulb is 3 068 cd/m^2 (Szokolay, 2008). The author (*ibid.*) alludes that lights with 25 000 cd/m^2 may result in glare when directly sensed by human eyes.

Furthermore, summer and winter days indoor luminance of various spaces on the ground floor of the building were also simulated and presented in Figures 5.5 and 5.6.

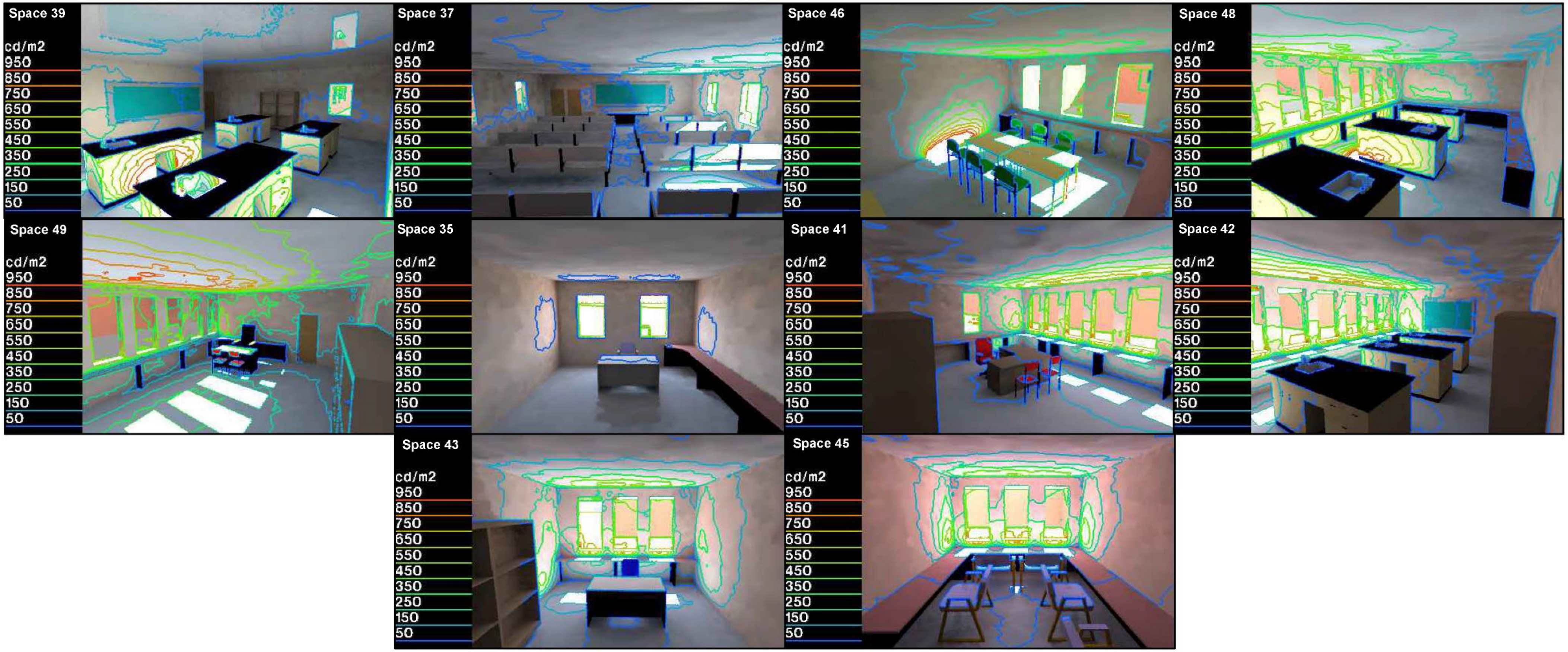


Figure 5.5: Simulated indoor luminance of the ground floor spaces on a typical summer day

Figure 5.6: Simulated indoor luminance of the ground floor spaces on a typical winter day

In Figures 5.5 and 5.6, 10 spaces in the building (including offices, laboratories and a lecture hall) were sampled. Spaces 37, 39, 46, 48, and 49 are located on the west side, space 35 is south facing, while spaces 41, 42, 43, and 45 are located on the east side. As in Figure 5.4, for spaces on the west side, indoor luminance was simulated at 16h30, while the luminance of spaces on the east side was simulated at 10h00. This corresponds to the periods of maximum ambient luminance at the building's west and east sides, as shown in Figure 5.4. A scale of 0 to 1000 cd/m^2 was adopted in Figures 5.5 and 5.6. Once again, the effect of the building orientation relative to the time and angles of sunrise and sunset were evident in Figures 5.5 and 5.6. Besides spaces 43 and 45, the average luminance of the spaces in summer was higher compared to levels in winter. Space 35 had the least luminance of 16.12 cd/m^2 in summer, while the lowest luminance of 2.96 cd/m^2 in winter was observed in space 49. In contrast, space 49 had the highest luminance of 216.96 cd/m^2 in summer, alongside space 46 with 77.46 cd/m^2 in winter. It is also evident in Figures 5.5 and 5.6 that the luminance of the spaces decreases as the distance from the windows increases. This was also noticed in spaces 46, 48, 49, 41, 42, 43, and 45 in the summer season. The highlighted spaces all have windows on one external wall such that daylight is received from one direction, which thus creates an uneven distribution of daylight indoors.

In addition to the luminance levels of the spaces, possible instances of visual discomfort due to glare were also analysed Based on Guth Visual Comfort Probability (GVCP) and Daylight Glare Index (DGI). Dolnikova and Katunsky (2019) define GVCP as the percentage of occupants who would be visually comfortable facing a specified direction relative to the light source in a space. The GVCP ranges from 0% to 100%, whereby 0% indicates that none of the occupants in the space would find their view path visually comfortable, while 100% means all the occupants would be visually comfortable with their view path. The author (*ibid*.:5) alludes that 70% GVCP is the acceptable benchmark, but computer tasks require 80%. In contrast, DGI is the degree of visual discomfort of an occupant relative to the view path and the light origin (Bellia, Cesarano, Iuliano and Spada, 2008). DGI ranges from ≤16, which is considered "just imperceptible", to >28, which is considered "intolerable" (Detsi, Manolitsis, Atsonios, Mandilaras and Founti, 2020). Based on Figures 5.5 and 5.6, the simulated GVCP and DGI of the ground floor spaces are summarised in Appendix C-1.

Similarly, the indoor luminance of space for the top floor spaces on typical summer and winter days are presented in Figures 5.7 and 5.8, respectively. The spaces sampled consist of four laboratories, five offices, and a lecture hall. Spaces 18, 22, and 23 are located on the west side of the building, while spaces 7, 11, 14, and 15 are located on the east side and spaces 3 and 5 are located on the south, with space 16 located on the north side. The highest luminance of 950.67 cd/m^2 was observed in space 16 in winter, while space 3 had the least luminance of 4.60 cd/m^2 in the same season. In the summer season, the same space (space 3) had the least luminance of 7.49 cd/m^2, while the maximum luminance of 151.15 cd/m^2 was observed in space 22. Also, the decrement of luminance away from the windows was observed in spaces 18, 11, 15, and 14 for both seasons. Based on Figures 5.7 and 5.8, the simulated GVCP and DGI analysis of the top floor spaces of the building are summarised in Appendix C-2.

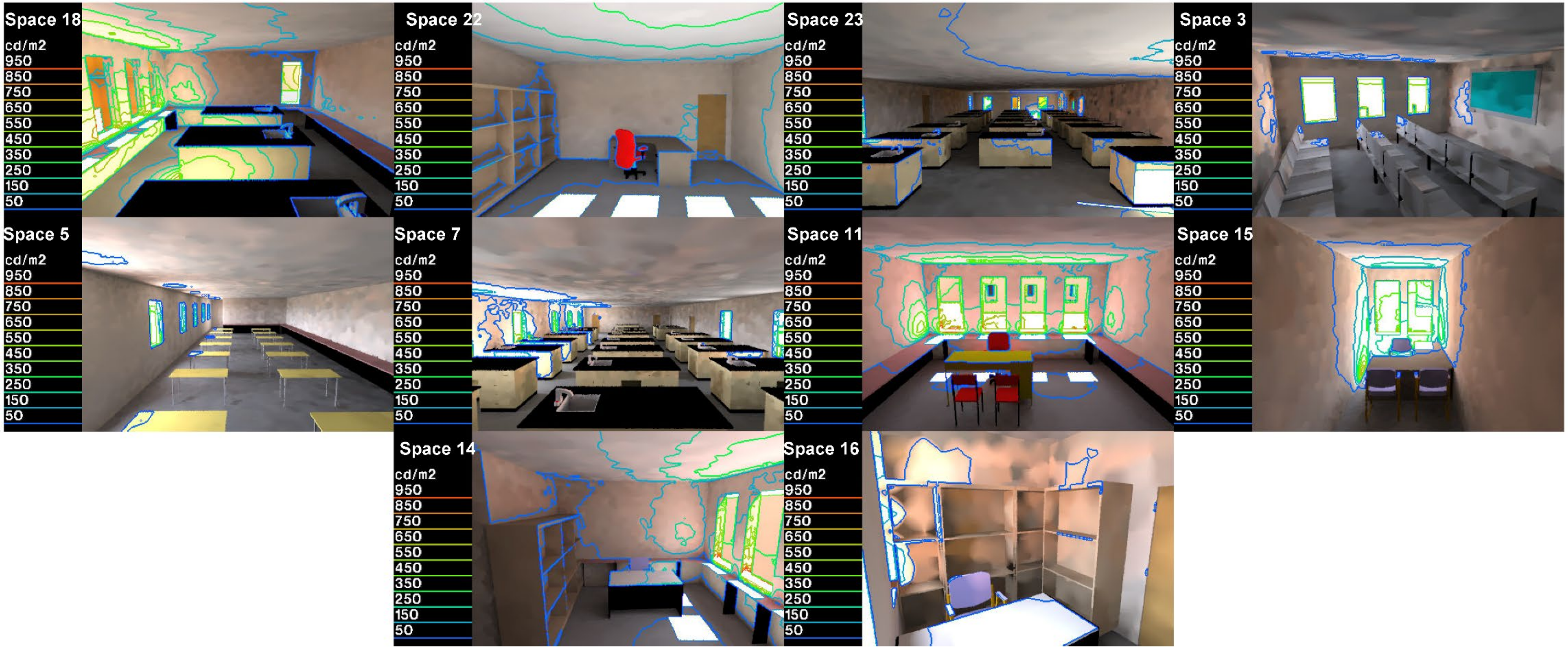


Figure 5.7: Simulated indoor luminance of the top floor spaces on a typical summer day

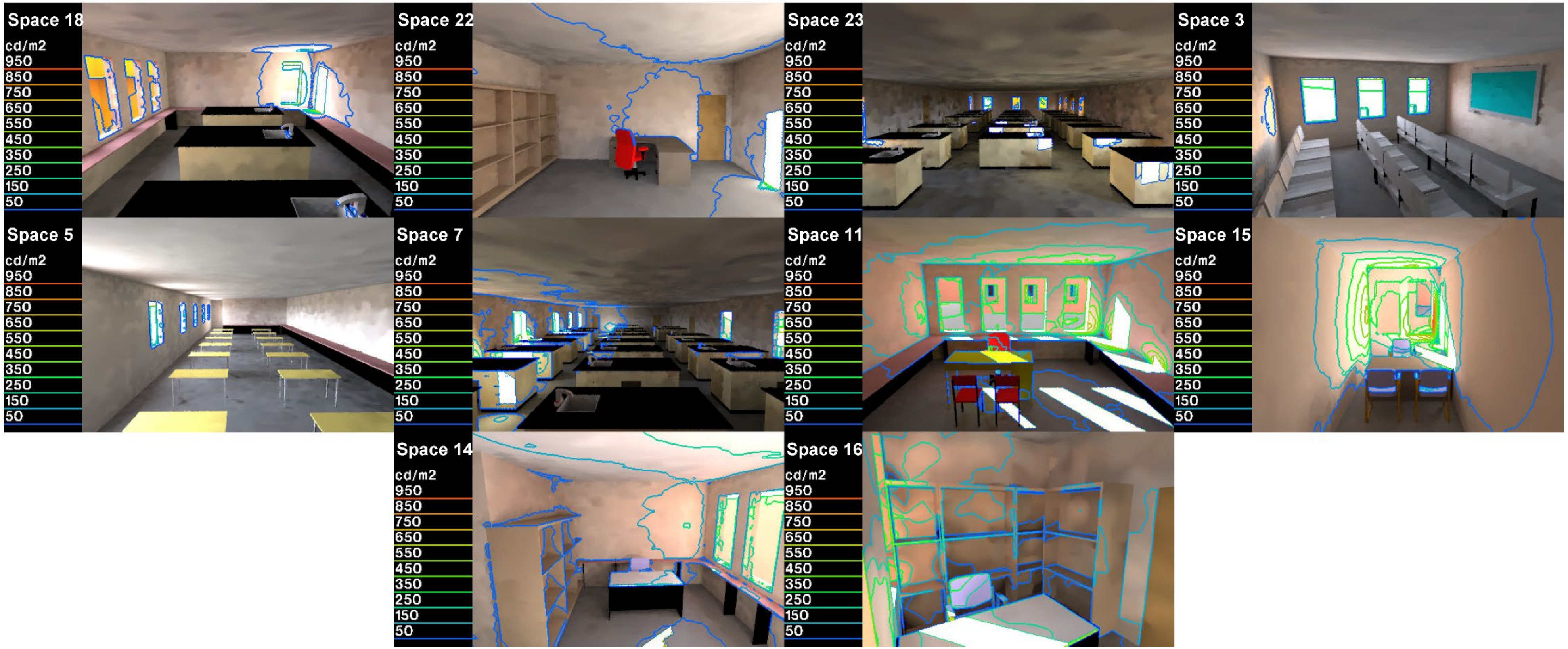


Figure 5.8: Simulated indoor luminance of the top floor spaces on a typical winter day

A comparison of luminance between ground floor and top floor spaces was conducted and presented in Table 5-2. In general, spaces to the west side of the building had the highest luminance levels with an average of 104.32 cd/m^2 in summer, while spaces to the south had the least luminance levels with an average of 5.18 cd/m^2 in winter. These do not include the north-facing office, which has an average luminance of 950 cd/m^2. In terms of storeys, the top floor spaces had the highest luminance, with an average of 47.39 cd/m^2 in summer and 123.96 cd/m^2 in winter. The average luminance levels for spaces on the ground floor was 75.39 cd/m^2 and 22.12 cd/m^2 in the summer and winter, respectively.

Table 5-2: Comparison of ground and top floor spaces luminance

Orientation	Summer		Winter	
	Ground floor (cd/m^2)	Top floor (cd/m^2)	Ground floor (cd/m^2)	Top floor (cd/m^2)
South	16.12	8.56	8.39	5.18
East	54.05	42.17	42.77	49.14
North	0.00	51.22	0.00	950.67
West	104.32	78.97	8.35	27.35

Seasonally, the highest average luminance of 73.04 cd/m^2 is experienced in winter, which was 11.65 cd/m^2 higher than the average luminance in summer. Nonetheless, spaces on the east side of the building experienced the most stable luminance, with an average of 47.03 cd/m^2 for both seasons and floors.

Theoretically, the luminance of a space is a factor of the amount of light, reflectivity, and the colour of materials. As indicated in Figures 5.5 to 5.8, bright coloured (white) surfaces tend to have higher luminance compared to dark (black) coloured surfaces. Indoor illuminance (actual levels of light in a space) was therefore analysed to categorically characterise daylight distribution. In line with Kruisselbrink *et al.* (2018), this was based on an imaginary grid of 1 m x 0.5 m and, as indicated by the red border lines, area of interest (AOI), which is 0.5 m away from the walls and windows of the spaces, was adopted. In addition, the building illuminance was simulated with a work plane of 0.85 m.

Further, Figures 5.9 and 5.10 show the indoor illuminance distribution for ground floor spaces on typical summer and winter days, respectively. The green shades indicate areas in the AOI with illuminance lesser than 300 lux.

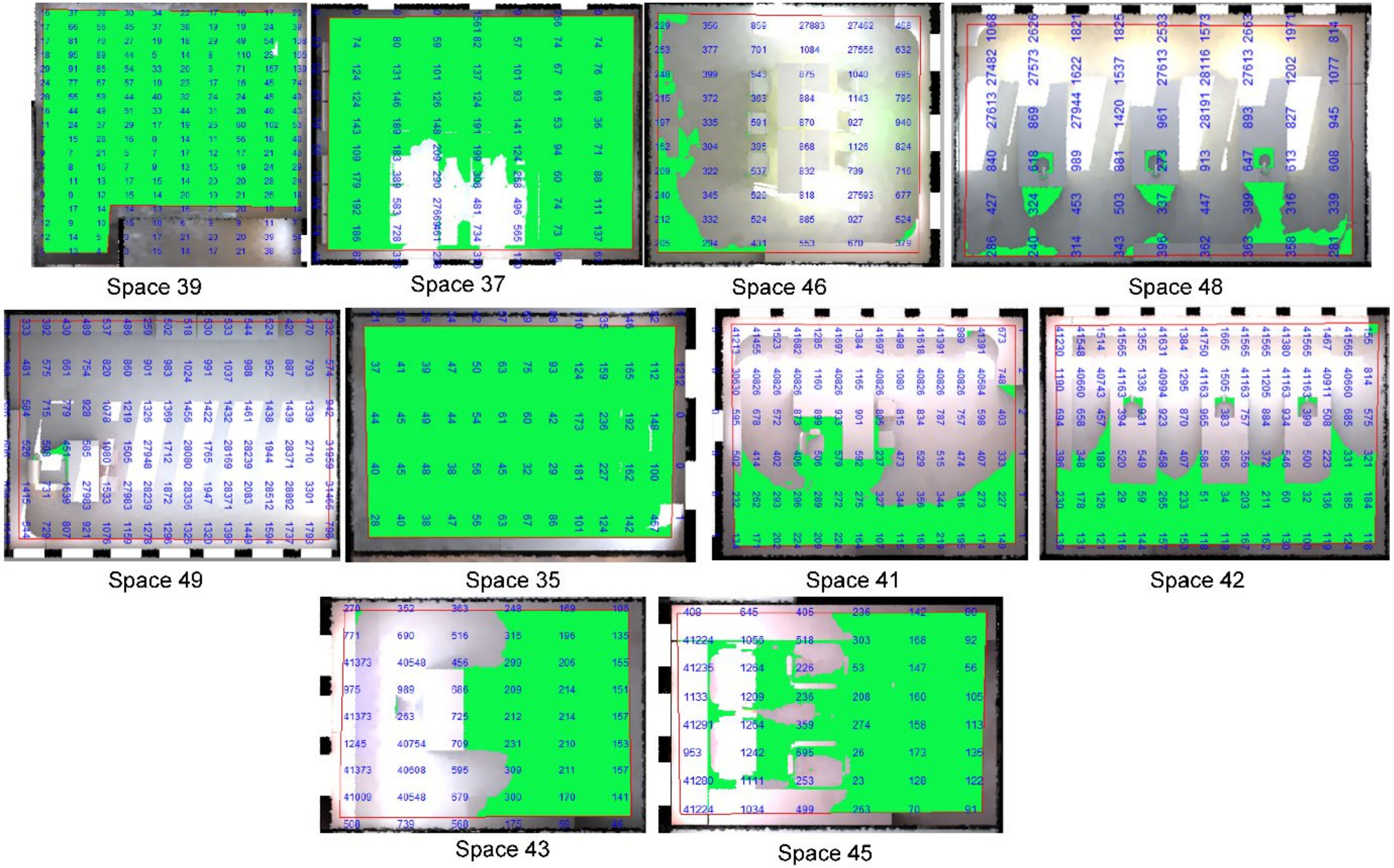


Figure 5.9: Simulated indoor illuminance of the ground floor spaces on a typical summer day

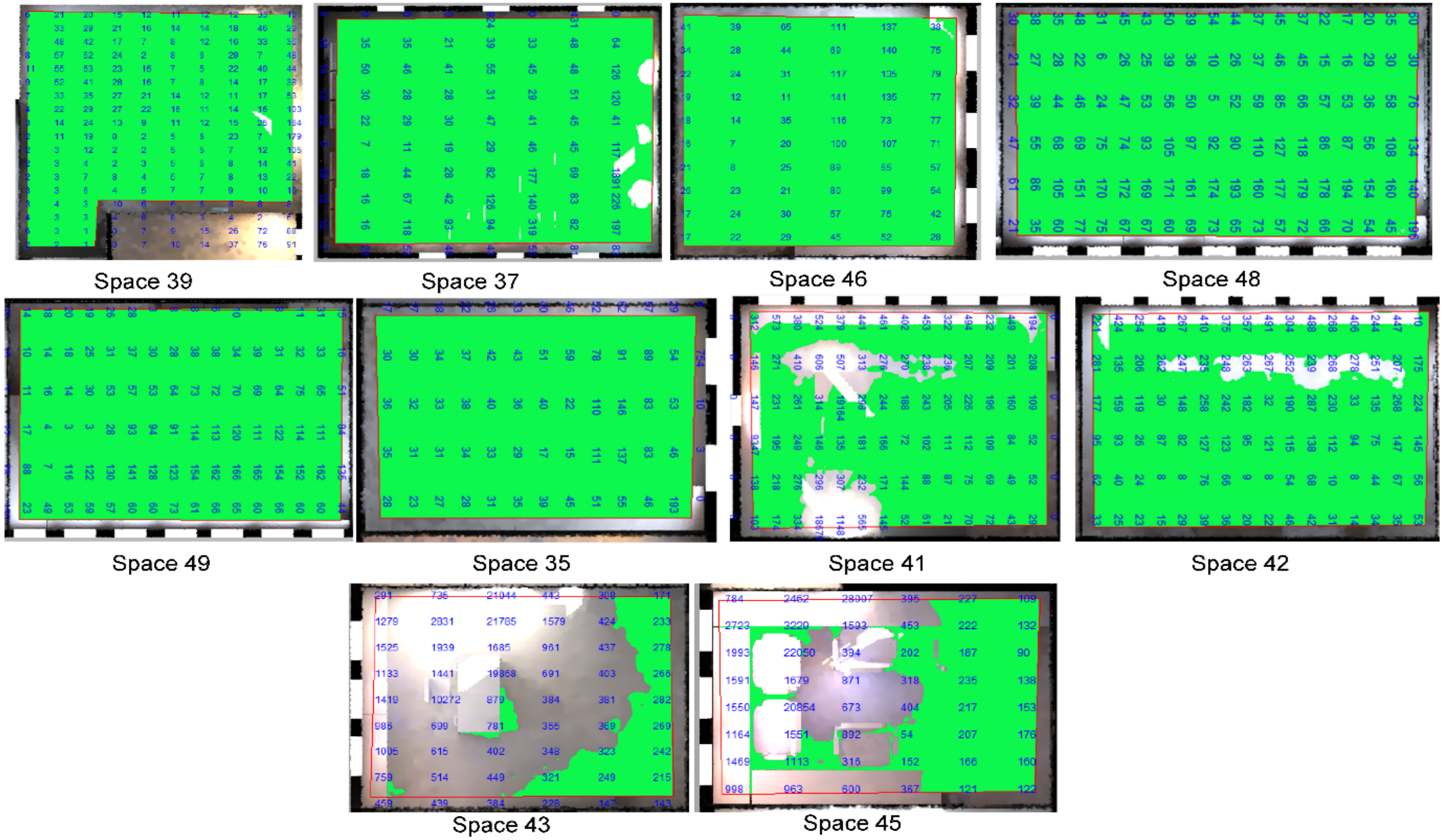


Figure 5.10: Simulated indoor illuminance of the ground floor spaces on a typical winter day

From Figure 5.9, spaces 41, 42, 43, 46, 48, and 49 experienced an average illuminance above 2 000 lux, while spaces 35, 37 and 39 had average illuminances below 1 000 lux. Space 39 was observed to have the least illuminance, with an average of 23.01 lux. The maximum average illuminance of the spaces was 6 347.04 lux and was observed in space 49. Comparing both seasons, the average illuminance in winter (509.90 lux) was 84% less than in summer (3 244.88 lux). From Figure 5.10, average illuminances above 1 000 lux were observed only in spaces 43 and 45. The maximum average illuminance observed was 2 237.69 lux for space 45, while space 39 had the lowest average of 35.30 lux. A statistical summary of Figures 5.9 and 5.10 is presented in Table 5-3.

Table 5-3: Statistical description of the building ground floor spaces illuminance

Space	Season	Minimum (Lux)	Maximum (Lux)	Average (Lux)	Uniformity	Diversity	AOI < 300 lux (%)
35	Summer	12.87	558.11	82.32	0.156	0.023	99.38
	Winter	7.12	299.55	47.76	0.149	0.024	100
37	Summer	5.14	35410.19	796.73	0.006	0	84.15
	Winter	0.94	4048.76	75.24	0.012	0	97.78
39	Summer	0.43	2976.64	23.01	0.019	0	99.88
	Winter	1.7	327.62	35.3	0.048	0.005	99.69
41	Summer	44.02	41713.18	4422.32	0.01	0.001	32.29
	Winter	6.34	21647.99	631.33	0.01	0	78.58
42	Summer	24.44	42084.58	4494.54	0.005	0.001	34.69
	Winter	6.54	743.92	138.09	0.047	0.009	88.51
43	Summer	12.93	41700.92	3644.55	0.004	0	49.0
	Winter	49.37	31038.13	1734.09	0.028	0.002	22.29
45	Summer	3.13	42031.59	4058.06	0.001	0	61.7
	Winter	4.71	45551.25	2237.69	0.002	0	45.88
46	Summer	87.54	45401.21	3564.94	0.025	0.002	8.34
	Winter	2.14	350.5	60.06	0.036	0.006	99.79
48	Summer	49.56	36809.83	5015.29	0.01	0.001	6.77
	Winter	2.28	304.87	73.56	0.031	0.007	99.99
49	Summer	109.92	30504.87	6347.02	0.017	0.004	0.31
	Winter	1.41	253.02	65.92	0.021	0.006	100

In the context of daylight, uniformity is the quality of daylight in the AOI, and it is mathematically defined as the ratio of the minimum to the average illuminance of the AOI (Kruisselbrink *et al.*, 2018). Diversity is the spread of daylight in the AOI, and it is mathematically expressed as the ratio of the maximum to the minimum illuminance of the AOI (Elsiana, Soehartono and Kristanto, 2020). In Table 5-3, relatively low daylight uniformity and diversity were observed in the spaces compared to the findings of Freewan and Al Dalala (2020). Unlike the case study building in this research, the authors (*ibid.*) assess the daylighting performance of passive solar-designed classrooms building in a Jordan University. The classrooms building daylight illuminance uniformity was found to be in the range of 0.15 to 0.66. Although the uniformity of both buildings was not expected to be equal, given the difference in their design, the comparison creates a perspective of modern building daylight illuminance uniformity and the impact of design on daylight distribution. Besides space 35, the illuminance uniformity of the spaces was below 0.1. As discussed in detail in Chapter 2, Section 2.4.1, the low uniformity of the spaces is due to the side-lighting strategy adopted in the building. Bradshaw (2006) emphasises that side-lighting is associated with poor indoor light quality due to possible blockage by adjacent structures outdoors and limited depth of diffusion relative to the position of the vertical windows. The furniture in the spaces, together with the side-lighting, also creates an uneven distribution of light in the space, thereby reducing illuminance uniformity and diversity.

Space 35 had higher uniformity and diversity of illuminances due to the lack of direct penetration of sun rays. Due to the same reason, space 35 was found to have the highest percentage AOI with illuminance lesser than 300 lux. In other words, the illuminances of 99.38% and 100% of space 35's AOI were less than 300 lux in summer and winter, respectively. In contrast, only 0.31% of space 49's AOI was found to have illuminance lesser than 300 lux in summer but shares the highest percentage AOI with illuminance less than 300 lux in winter. Moreover, space 43 had the most consistent daylight illuminance in both seasons, with only 49.0% and 22.29% of its AOI at illuminances less than 300 lux in summer and winter, respectively. Further, the indoor illuminance distribution of the top floor spaces of the building on typical summer and winter days is presented in Figures 5.11 and 5.12.

In Figure 5.11, 50% of the spaces (spaces 11, 14, 15, 18 and 22) have average illuminances greater than 2 000 lux. Space 22 had the highest average illuminance of 6 411.59 lux, while the least average illuminance of 69.29 lux was observed in space 5. The average illuminance of spaces 5, 3, 7, 16, and 23 was below 1 000 lux. A relatively smaller difference in illuminance (at 57%) was observed in the top floor spaces in summer and winter.

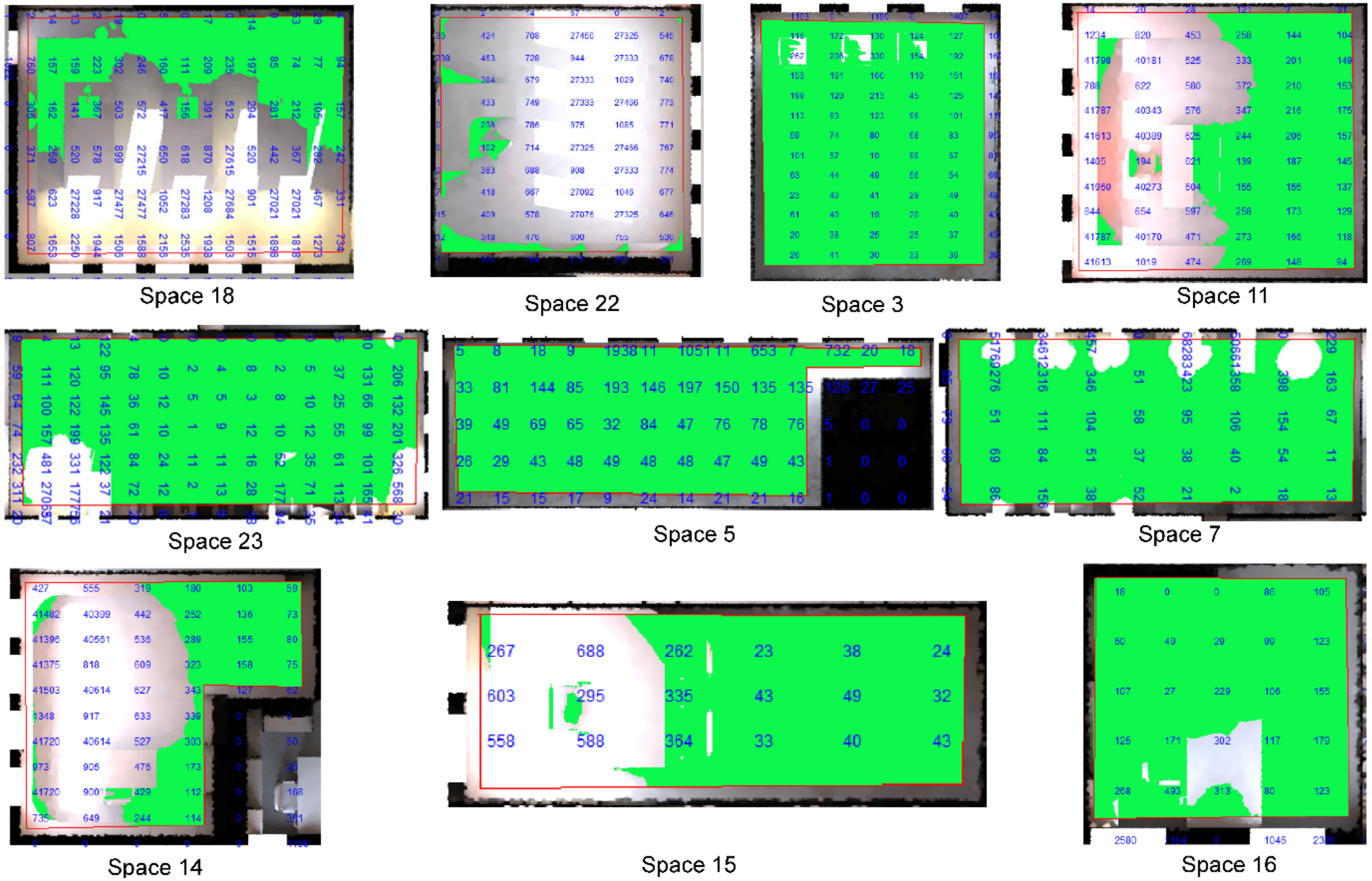


Figure 5.11: Simulated indoor illuminance of the top floor spaces on a typical summer day

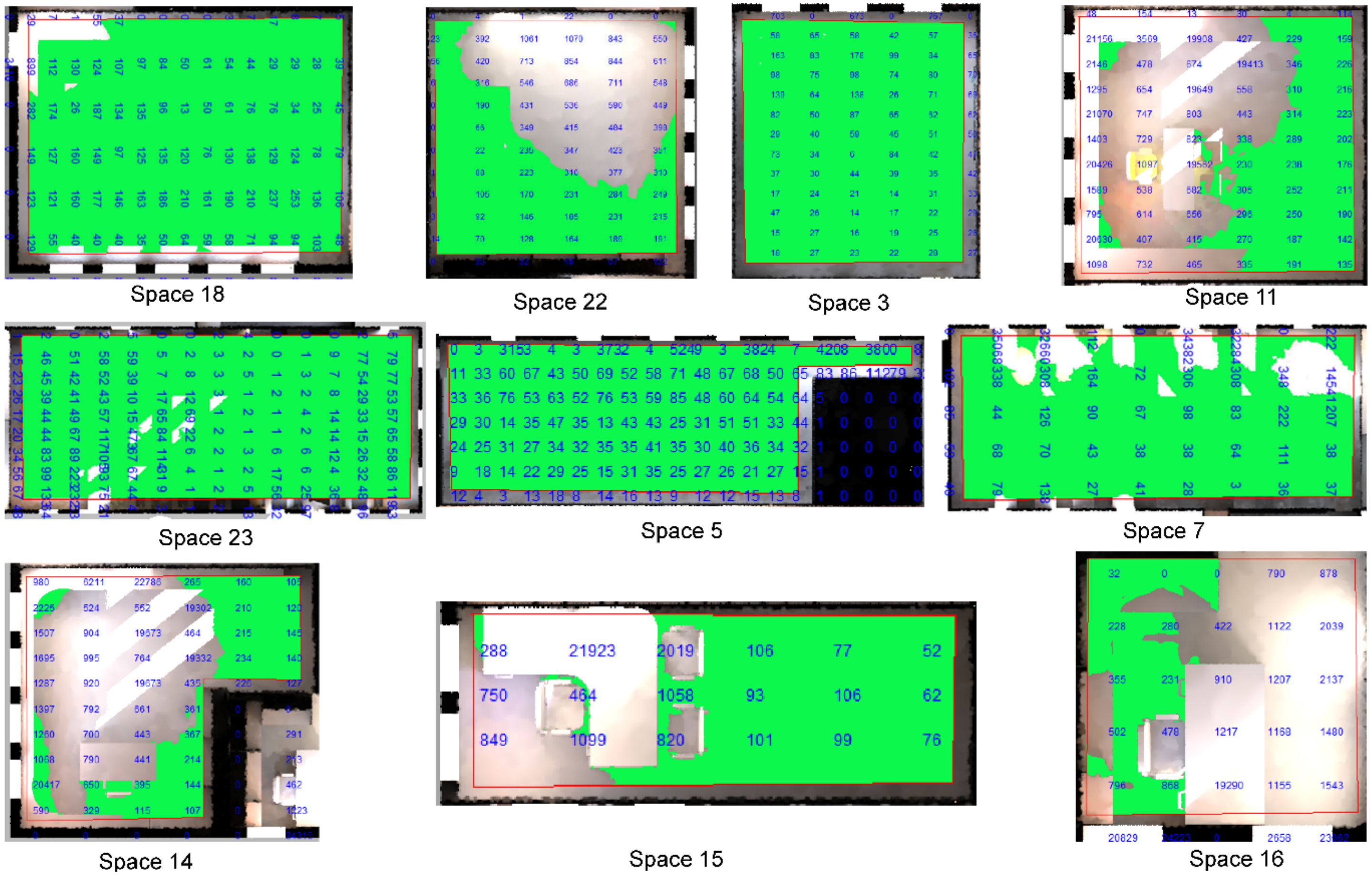


Figure 5.12: Simulated indoor illuminance of the top floor spaces on a typical winter day

In Figures 5.11 and 5.12, the average illuminance of spaces 11 and 14 were above 2 000 lux, while that of spaces 15 and 18 was above 1 000 lux but below 2 000 lux, and the illuminance of the other spaces was below 1 000 lux. Spaces 14 and 5 had the highest and least average illuminances of 2 507.81 lux and 38.37 lux, respectively. Table 5-4 contain a statistical description of Figures 5.11 and 5.12.

Table 5-4: Statistical description of the building's top floor spaces illuminance

Space	Season	Minimum (Lux)	Maximum (Lux)	Average (Lux)	Uniformity	Diversity	AOI < 300 lux (%)
3	Summer	2.06	564.68	87.59	0.024	0.004	98
	Winter	1.05	432.56	51.24	0.021	0.002	99.99
5	Summer	5.9	282.64	69.29	0.085	0.021	100
	Winter	2.2	157.79	38.37	0.057	0.014	100
7	Summer	1.22	54804.93	807.47	0.002	0	90
	Winter	1.2	37544.01	842.8	0.001	0	85
11	Summer	69.4	42017.08	3651.9	0.019	0.002	49.87
	Winter	101.95	31573.65	2507.81	0.041	0.003	38.07
14	Summer	0.86	41720.25	4872.37	0	0	36.99
	Winter	2.22	26260.58	2904.01	0.001	0	33.43
15	Summer	0.7	43713.34	3980.02	0	0	64.23
	Winter	5.14	33727.72	1712.28	0.003	0	58.77
16	Summer	0	831.12	125.41	0	0	91.34
	Winter	0	28026.93	1779.03	0	0	26.76
18	Summer	16.51	36577.68	3789.54	0.004	0	32.58
	Winter	3.46	4558.46	146.23	0.024	0.001	95
22	Summer	0.07	27706.79	6411.59	0	0	6.07
	Winter	0.06	3785.92	362.05	0	0	52.18
23	Summer	0.37	42787.05	596.06	0.001	0	90.52
	Winter	0.09	2469.29	62.64	0.001	0	98.07

As evident in Table 3-4, a relatively low illuminance uniformity and diversity were observed for top floor spaces where only spaces 3 and 5 (south-facing spaces) where illuminance uniformity and diversity were greater than 0.01 in both seasons. As indicated earlier, this can be attributed to the absence of direct sun rays in south-facing spaces. Both south-facing spaces recorded the highest percentage AOI with illuminance lesser than 300 lux. Although space 22 had the least percentage AOI of 6.07%, with illuminance less than 300 lux. Space 14 was found to have the most consistent illuminance distribution in both seasons.

5.3 Whole-building (as-is) Energy Performance

This section covers the whole-building energy performance of the case study building but mainly focuses on the energy use intensity (EUI). In this regard, only electric lighting and energy-use of appliances in conditioned spaces were considered in the simulation. In the context of building energy performance, conditioned spaces or zones are areas in a building that are thermally conditioned mechanically or electrically for thermal comfort. Conditioned spaces therefore exclude hallways, toilet/bathroom, storage, and garage. The lights and appliance energy-use simulation were based on Appendix A-1 and A-2 together with the University of Fort Hare Faculty of Science and Agriculture 2018 prospectus. The building energy performance simulation was initiated by creating the building lighting and appliances' demand profiles based on the academic schedule in the prospectus. Table 5-5 contains the major schedules of the building that were adopted in the simulation.

Table 5-5: Schedule for energy performance simulation of the building

<table>
<tr><th>Schedule/profile</th><th>Daily</th><th>Weekly</th><th></th><th colspan="2">Annual</th></tr>
<tr><td>Lecturers</td><td>08h00 – 16h30</td><td>Mon. – Fri.</td><td rowspan="5">Staff</td><td>01 Jan – 14 Jan</td><td>Holiday</td></tr>
<tr><td rowspan="2">Lectures/researchers</td><td>08h00 – 16h30</td><td>Mon – Fri.</td><td>15 January – 14 June.</td><td>In session</td></tr>
<tr><td>10h00 – 19h00</td><td>Sat. – Sun.</td><td>15 Jun – 14 Jul</td><td>Exam/holiday</td></tr>
<tr><td rowspan="2">Cleaners</td><td rowspan="2">07h00 – 15h00</td><td rowspan="2">Mon. – Fri</td><td>15 Jul – 15 Dec</td><td>In session</td></tr>
<tr><td>16 December – 31 December.</td><td>Exams/holiday</td></tr>
<tr><td>Postgraduate classes</td><td>15h00 – 18h00</td><td>Tue, Wed, & Fri.</td><td rowspan="7">Students</td><td>01 January – 31 January.</td><td>Holiday</td></tr>
<tr><td>Undergraduate classes</td><td>08h00 – 13h30</td><td>Mon – Fri.</td><td>01 February – 31 May</td><td>In session</td></tr>
<tr><td>First-year Mechanics practical</td><td>14h00 – 17h30</td><td>Mon. – Fri.</td><td>01 June – 15 July</td><td>Exam/holiday</td></tr>
<tr><td>First-year electrical practical</td><td>08h00 – 17h30</td><td>Mon. – Fri.</td><td rowspan="2">16 July – 15 October.</td><td rowspan="2">In session</td></tr>
<tr><td>Optics practical</td><td>14h00 -16h30</td><td>Tue. & Thur.</td></tr>
<tr><td>Second-year practical</td><td>14h00 – 17h30</td><td>Tue. & Thur.</td><td rowspan="2">16 October – 31 December.</td><td rowspan="2">Exam/holiday</td></tr>
<tr><td>Third year practical</td><td>14h00 – 17h30</td><td>Tue. & Fri.</td></tr>
</table>

As indicated in Table 5-5, the energy schedules of the building consist of activities during weekdays and weekends. From Figure 4.7, it was observed that some of the offices operate until late (20h00) hours of the weekdays and on weekends as well. This was used to guide the development of the building energy usage schedules. From Table 5-5, the daily hours of occupancy were used to develop the weekly schedules of all conditioned spaces in the building, which were then integrated into an annual schedule, taking the outlined holidays into consideration. It is worth noting that only major academic breaks such as mid-year and end-of-year breaks were considered. The annual schedule in Table 5-5 was also used to create the lights and appliances' schedules in the conditioned spaces. It was assumed that during the occupancy period, all the lights and appliances were switched on. However, appliances in this context refer to personal desktops and laptop computers. The operation of other appliances, such as electric kettle, telephone set, electric heater, fan, and air conditioner, were assigned different operating profiles. Figures 5.13 and 5.14 show the average simulated summer and winter demands of electric lights and appliances.

In Figures 5.13 and 5.14, interior lighting represents all electric lights on the ground and top floor conditioned spaces. The receptacle equipment consists of desktop computers, laptops, printers, telephone sets and laboratory apparatus. As indicated earlier, desktop computers, laptops, and speakers share the same operating profile as the lights in their respective spaces. The printers were scheduled to operate at 10% capacity from 08h00 to 16h30 for spaces only occupied during the weekdays and from 08h00 to 20h00 for those spaces occupied on weekdays and weekends. The operating profile of the printers is due to the intermittent use of printers in a typical office setting. The operation of the laboratory apparatus was scheduled according to their respective time frames, as outlined in Table 5-5. Further, the power demand of electric kettles is represented by cooking, while other process indicates the demand for electric heaters. Other process and interior local fan (a combination of fans and air conditioners demands) were scheduled based on the indoor air temperature of their respective spaces. Specifically, fans and air conditioners were scheduled to turn on when the indoor air temperature was above 24°C, while electric heaters were only switched on when the air temperature was below 20°C. The indoor air temperature threshold is based on the South African Bureau of Standards (2011) indoor air temperature setpoint recommendation.

Typical summer weekdays average demand of the interior fan was set at 1.88 kW, while the average demand of the electric heaters was set at 0 kW. On winter weekdays, the interior fan average demand was reduced by 1.72 kW, while the average demand for electric heaters was increased by 0.46 kW, as indicated by other process in Figures 5.13 and 5.14. In both seasons, all other appliances maintained a constant average demand of 2.50 kW for interior lighting, 3.60 kW for receptacle equipment, 0.12 kW for cooking and 0.14 kW for refrigeration.

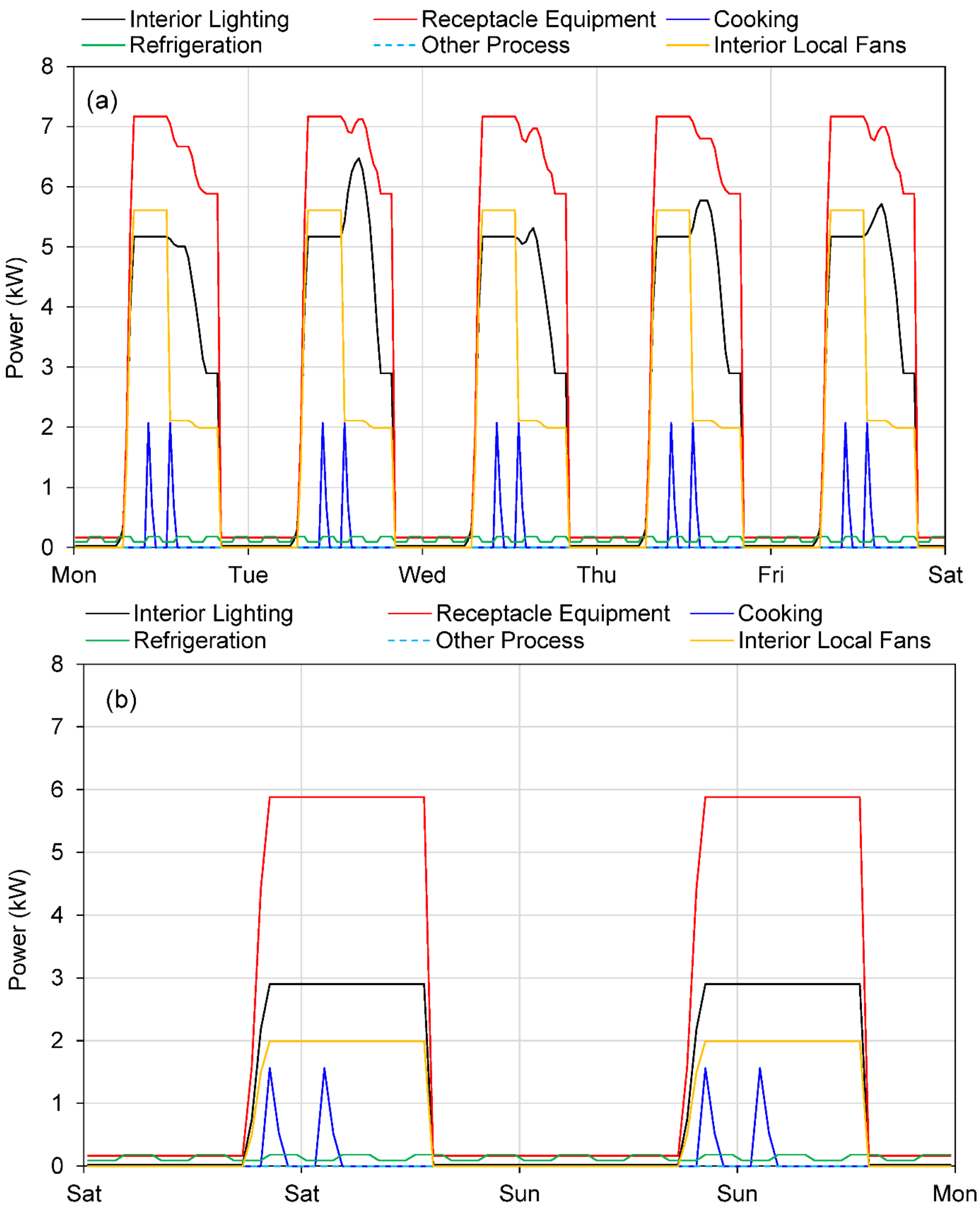


Figure 5.13: Simulated average summer lighting and appliances demand on (a) typical weekdays and (b) typical weekend

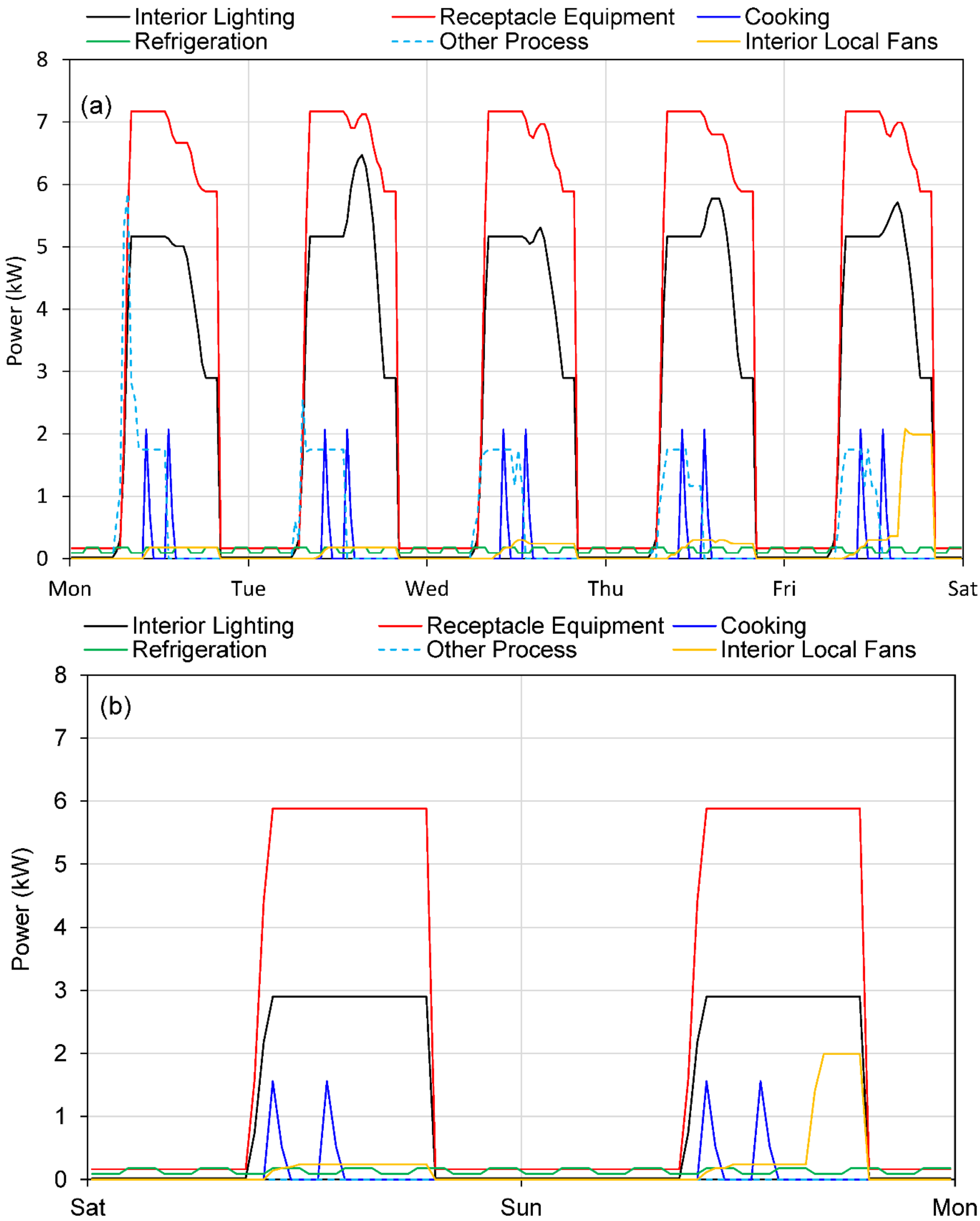


Figure 5.14: Simulated average winter lighting and appliances demand on (a) typical weekdays and (b) typical weekend

On weekends, the average demand for electric heaters was 0 kW in both seasons, while the average demand for interior local fans was set at 0.79 kW and 0.19 kW for summer and winter, respectively. Interior lighting, receptacle equipment, cooking and refrigeration average demands were respectively 1.6 kW, 2.43 kW, 0.09 kW and 0.149 kW in both seasons. The building's monthly energy use is presented in Figure 5.15

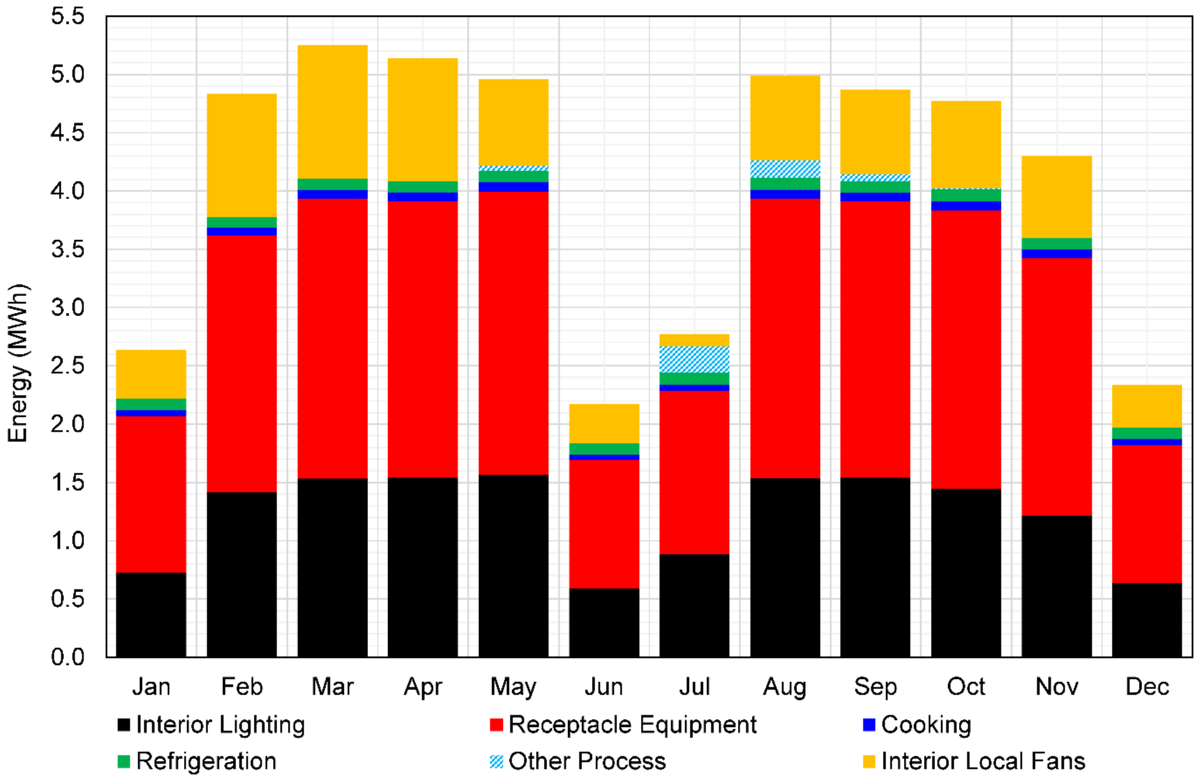


Figure 5.15: Simulated monthly energy consumption of the building

Based on Figure 5.15, energy consumptions for January, June, July, and December were relatively low, with an average of 2.48 MWh, which is approximately 50% lower than the average consumption for the other months. The low consumption is because of holidays, as outlined in Table 5-5. Heating energy consumption, as indicated by "other process", was only noticeable in May, July, August, and September, with an average of 0.50 MWh, which is 94% lower than indoor local fan average energy consumption. These findings are in line with the average seasonal outdoor air temperature for Alice (Overen *et al*., 2019). In general, receptacle equipment had the highest energy consumption, with a total of 23.80 MWh/year. This is followed by lighting energy consumption, with a total of 14.64 MWh/year. The percentage energy-use of appliances and lights is presented in Figure 5.16.

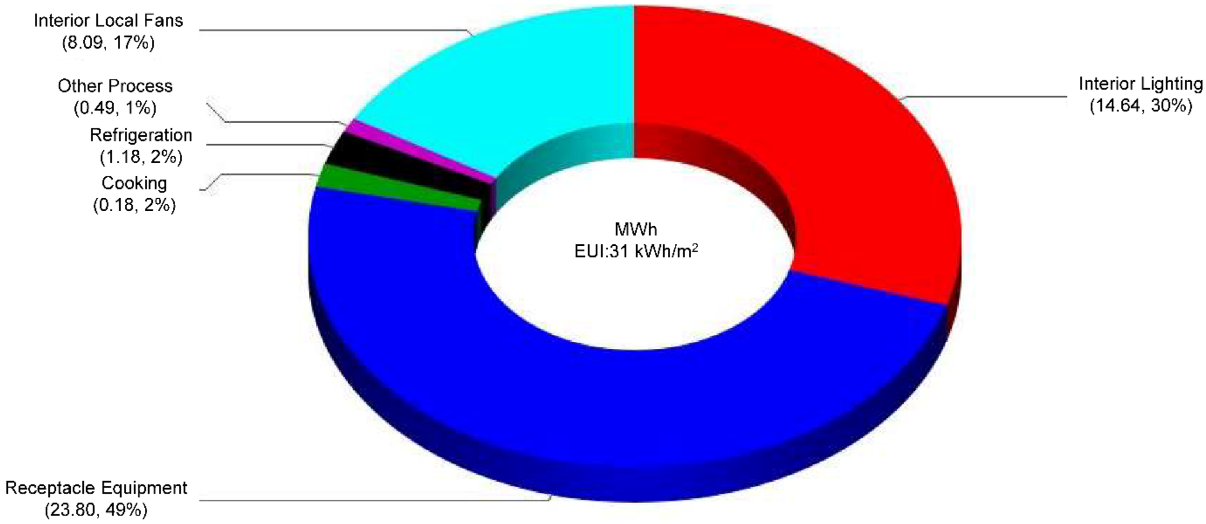


Figure 5.16: Simulated building electrical appliances and lights energy usage and overall energy use intensity

Receptacle equipment accounts for approximately half of the building's total energy consumption, while lighting is responsible for 30%. Interior local fan consumes 17% of the total energy, and heating is responsible for only 1%. The annual scheduled holidays significantly reduce the heating energy consumption as the major heating season (in June and July) was omitted in the simulation. Lastly, cooking and refrigeration account for 2% of total energy consumption. In general, the overall EUI with respect to conditioned spaces is 31 kWh/m^2. As discussed in Section 5.3, non-conditioned spaces were excluded because they are considered unhabitable spaces and thus do not technically contribute to the building EUI according to SANS 204 (South African Bureau of Standards, 2011). The annual energy profile for the building was extracted from Figure 5.15 and used to derive operational energy cost, as presented in Figure 5.17.

Following the tariff-setting approach discussed in Section 4.2.3, an average energy tariff of 1.12 R/kWh in summer and 2.35 R/kWh in winter was used to derive the building energy cost. The average tariffs were obtained from the seasonal TOU energy charges in Table 4-5. In Figure 4.27, the highest energy cost was expected in the winter months given the high demand charges, but due to holidays, June's energy cost was relatively low, with R 5 103.26, while the highest energy cost of R 11 714.52 was observed in August. Similarly, January and December had the lowest energy cost of R 2 951.87 and R 2 612.18, respectively. This is attributed to the end-of-year holiday considered in the annual schedule.

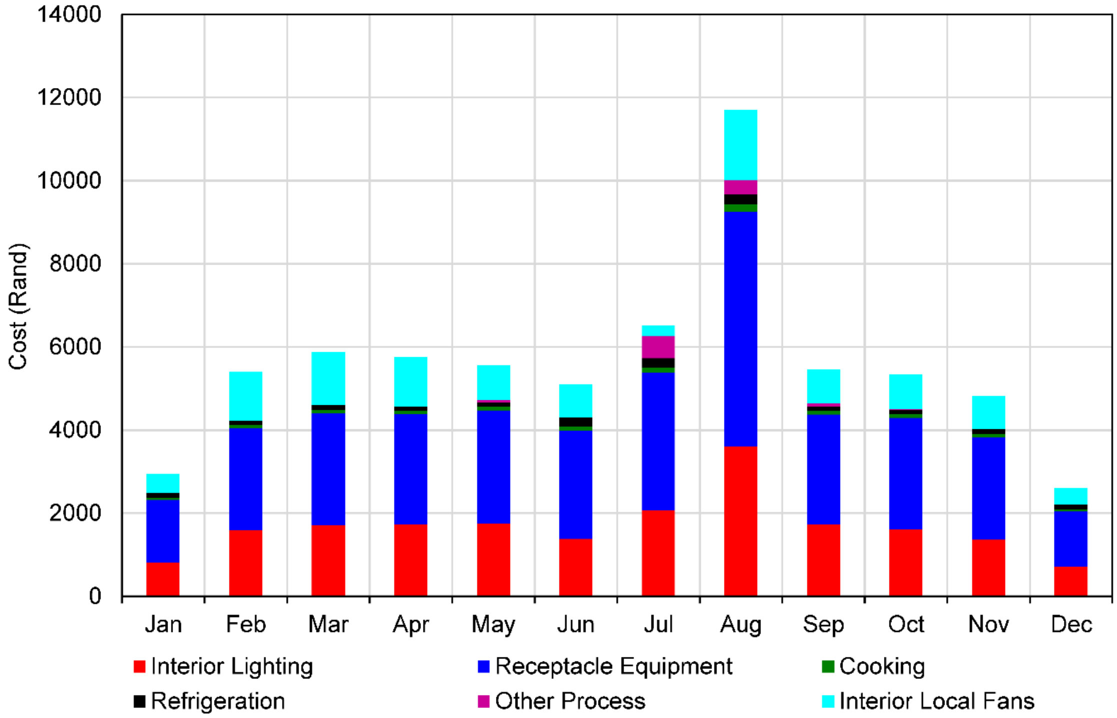


Figure 5.17: Simulated monthly energy cost of the building

Moreover, the cumulative annual energy cost for the building is R67 107.75, which is equivalent to an average cost of R5 592.31/month. The respective annual energy cost of the various appliances and lights are presented in Figure 5.18.

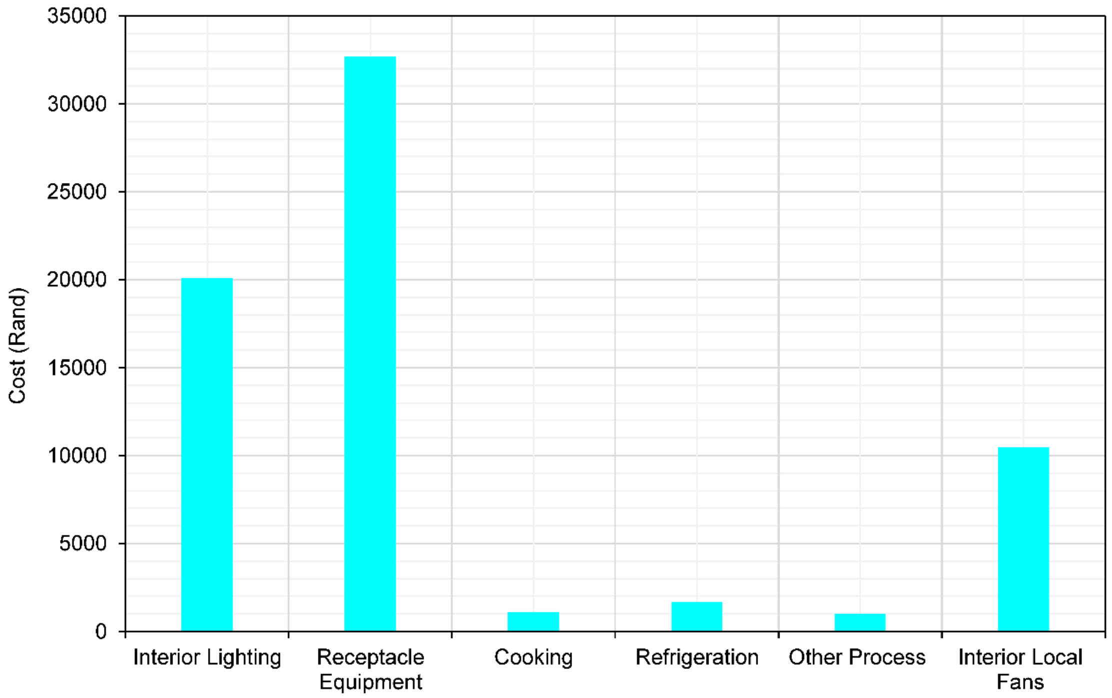


Figure 5.18: Simulated total energy cost for appliances and lights

As shown in Figure 5.18, receptacle equipment and interior lighting energy cost were more than 50% higher than the energy costs of other appliances. Interior lighting accrued R20 091.86 per year. Seasonally, lighting energy amounted to R54.51 per day in summer and 116.46 per day in winter. However, receptacle equipment had the highest energy cost of R32 702.14 per year, averaging R86.82 per day in summer and R181.87 per day in winter. The overall daily average operational energy cost was R181.25 in summer and R377.80 in winter.

The resultant GHG emissions impact due to the whole-building energy use is illustrated with the CO_2 emissions bar chart in Figure 5.19. CO_2 emissions due to energy-use of appliances were further consolidated into total system emissions, which represent the interior fan CO_2 emissions, other processes (heating), while receptacle equipment CO_2 emissions were captured as total equipment and total lights represent interior lighting CO_2 emission.

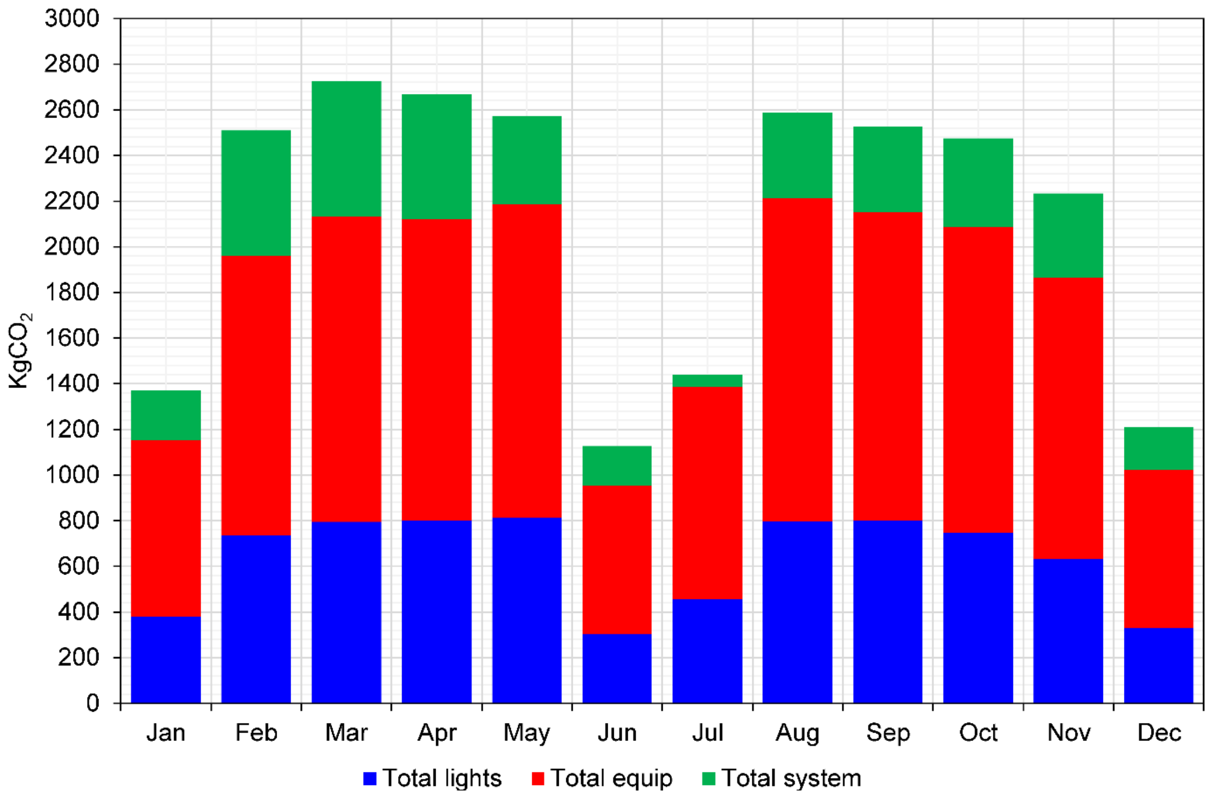


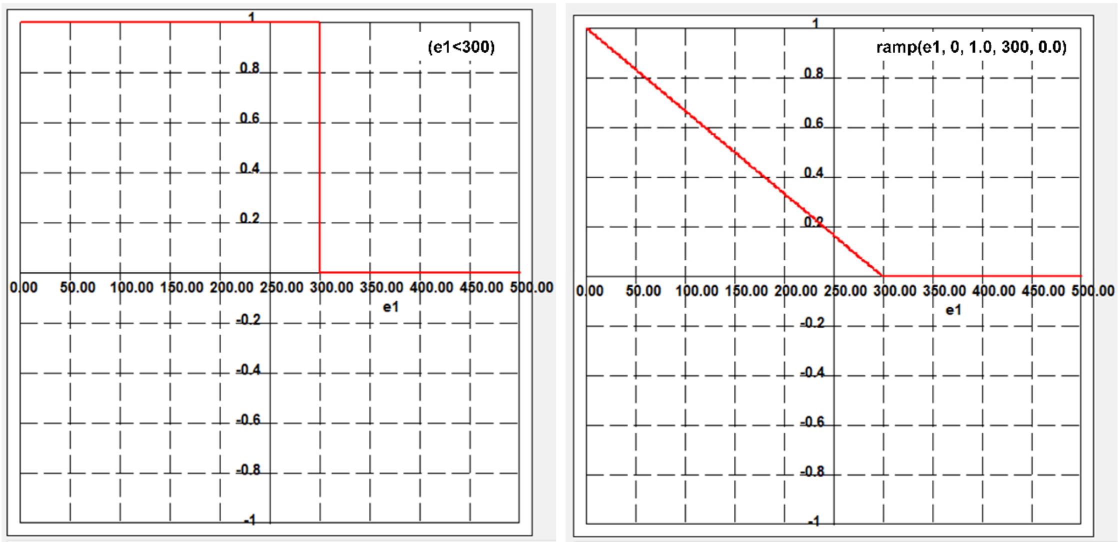
Figure 5.19: Simulated environmental impact of the building energy consumption

CO_2 emission for total lights was 7 596 kg per annum, but total equipment had the highest emissions of 13 942 kg per annum. System CO_2 emissions were the least at 4 201 kg per annum. Cumulatively, the annual energy consumption of the building was equivalent to 25 440 kg of CO_2 emission, which averages at 2 120 kg of CO_2 emissions per month.

5.4 Lighting Energy Optimisation of the Building: Daylight-linked Interventions

A non-invasive daylight intervention was prioritised for the study in order to avoid interference with the façade of the building, given its heritage status. In line with Atif and Galasiu (2003), Alrubaih *et al.* (2013), and Lim *et al.* (2017), daylight-linked sensors were adopted in the research. Automated on/off and continuous dimming daylight interventions were employed to optimise the building lighting energy consumption. Figure 5.20 shows the automated on/off and continuous dimming daylight-linked equation graphs used in the simulation.

From Figure 5.20, the automated on/off sensors were programmed to switch off the lights in a given space when the indoor illuminance is greater than 300 lux and on when the illuminance is below 300 lux. In other words, the electric lights in the space operate at 0% of their rated capacity when the indoor illuminance is above 300 lux and at 100% capacity when the illuminance is below 300 lux. On the other hand, a regression algorithm was adopted in



Automatic on/off Continuous dimming

Figure 5.20: Automatic and continuous dimming equation graphs

continuous dimming sensors. The lights' operating capacity in a given space decreases from 100% to 0% as the indoor illuminance of the space increase from 0 lux to 300 lux. Further, the automated on/off and continuous dimming daylight-linked energy performances were simulated consecutively and compared with the building "as-is" energy performance as covered in Chapter 4. It is noteworthy that the daylight-linked sensors schedule operates in parallel with the building's "as-is" lighting schedule, i.e., the lights must be switched on by the occupant for the daylight-linked sensors to operate (Lim *et al.*, 2017). Also, in line with Lim *et al.* (2017) approach, the sensors were installed on the ceiling facing downward. The graphical comparison of automated on/off, continuous dimming and "as-is" lighting demand of the building on summer and winter weekdays and weekends is presented in Figures 5.21 and 5.22.

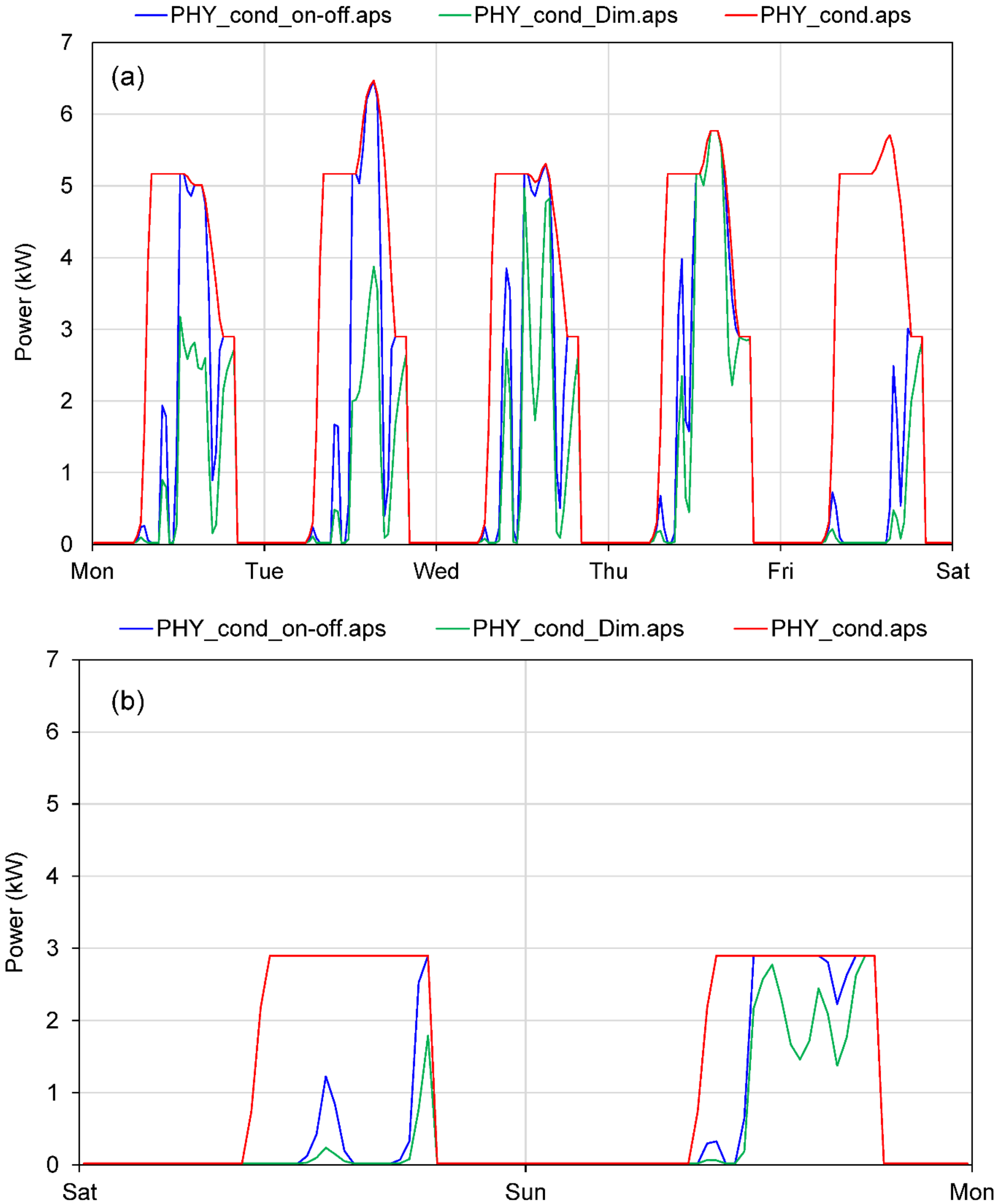


Figure 5.21: Simulated “as-is” and daylight interventions electric lighting demand on (a) summer weekdays and (b) summer weekends

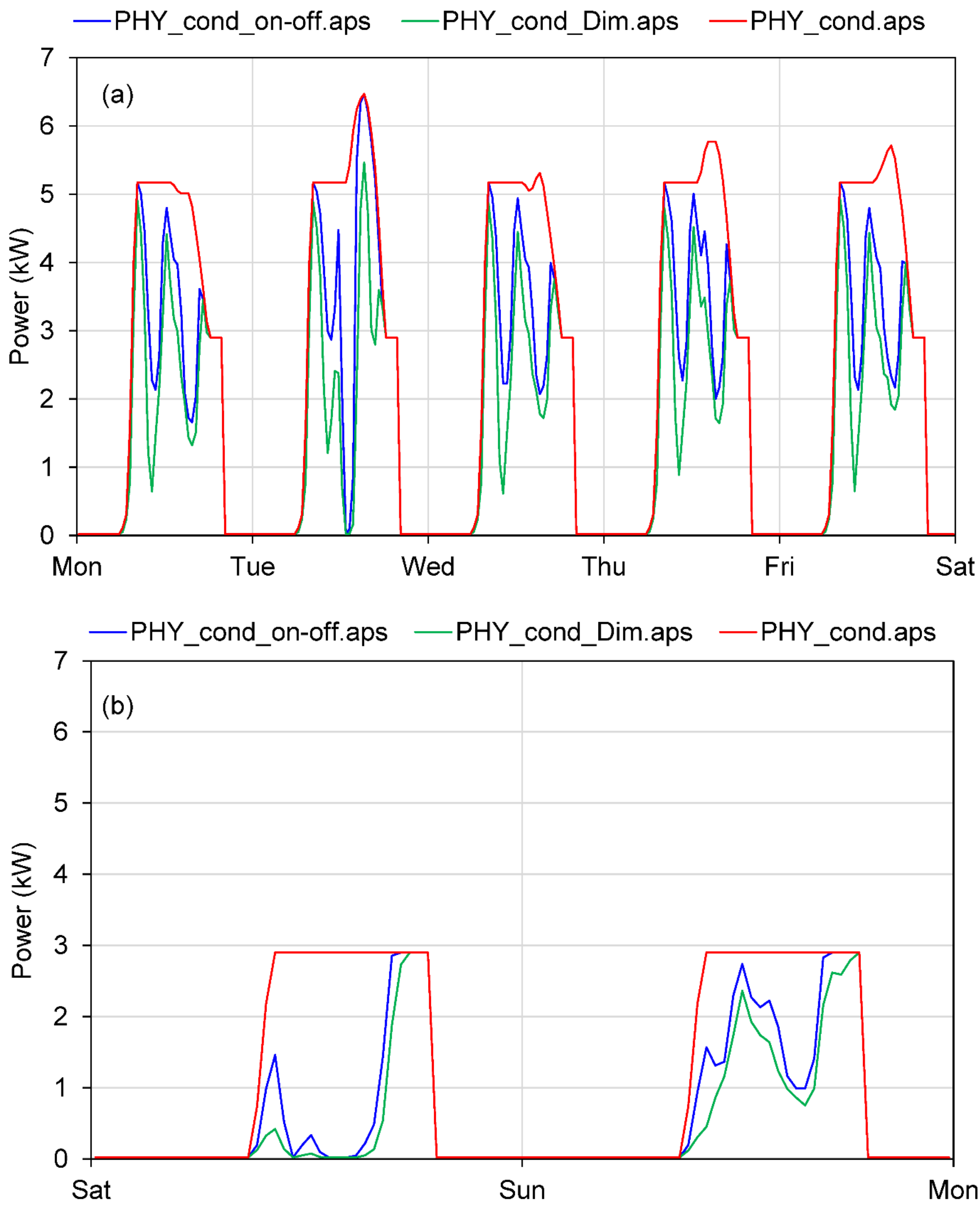


Figure 5.22: Simulated “as-is” and daylight interventions electric lighting demand on (a) winter weekdays, and (b) winter weekends

In Figures 5.21 and 5.22, PHY_cond_on-off represents automated on/off lighting demand, PHY_cond_Dim was used to indicate continuous dimming lighting demand, while PHY_cond was used to represent the “as-is” lighting demand of the building. On summer weekdays, the average automated on/off and continuous dimming lighting demands were 1.33 kW and 0.86

kW, respectively. This is equivalent to a 47% reduction in lighting demand due to automated on/off sensors and 65% due to continuous dimming sensors. In summer weekends, the lighting demand was further reduced to 54% by automatic on/off sensors and 68% by continuous dimming sensors. In Figures 5.13, 5.14, 5.21 and 5.22, the “as-is” average weekdays lighting demand and average weekends lighting demand were respectively constant regardless of the season. This was not the case for automated on/off and continuous dimming sensors, as their lighting demands vary from one day to another depending on available solar radiation. Therefore, summer lighting energy demand reduction is expected to differ from winter demand reduction.

The average winter weekday automated on/off lighting demand was 1.84 kW, equivalent to 26% demand reduction, while continuous dimming lighting demand was 1.50 kW, equivalent to 40% demand reduction. In winter weekends, automated on/off and continuous dimming average lighting demand were 0.62 kW and 0.49 kW, respectively, equivalent to 47% demand reduction for automated on/off sensors and 58% for continuous dimming sensors. A synopsis of the building “as-is” and the daylight interventions' seasonal and annual lighting demands are presented in Table 5-6.

Table 5-6: Seasonal and annual “as-is” and daylight interventions lighting energy demand of the building

Lights operation	**Summer**		**Winter**		**Annual**	
	Mean (kW)	Reduction (%)	Mean (kW)	Reduction (%)	Mean (kW)	Reduction (%)
Automated on/off	0.80	55	0.81	40	0.80	52
Continuous dimming	0.60	66	0.63	53	0.61	64
No sensor (as-is)	1.77	0	1.36	0	1.67	0

Table 5-6 shows a 15% difference between summer and winter for automated on/off lighting demand reduction and 13% for continuous dimming lighting energy demand reduction. Continuous dimming operation had the most lighting demand reduction, with 66% in summer and 53% in winter. On average, the building’s annual lighting demand was reduced by 52% with automated on/off sensors and 64% with continuous dimming sensors. The building’s monthly optimised lighting energy is presented in Figure 5.23.

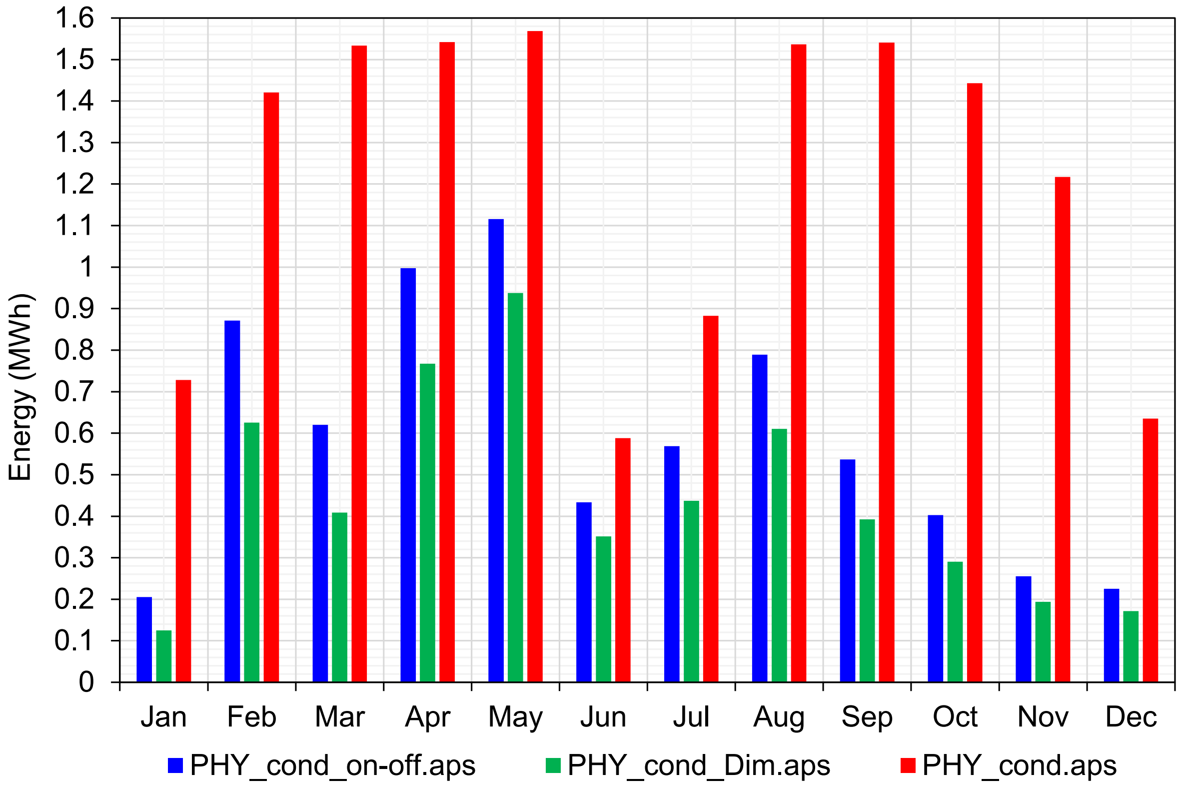


Figure 5.23: The building's monthly "as-is" versus optimised light energy consumption

Continuous dimming sensors were found to contribute the least energy consumption of 0.44 MWh per month, while automated on/off sensors contributed 0.59 MWh per month. The contribution to the building total energy reduction of automated on/off and continuous dimming was 16% and 20%, respectively, compared to "as-is" lighting energy consumption.

Further, the percentage contribution to the reduction in energy consumption of the automated and continuous dimming sensors relative to other appliances in the building is presented in Figure 5.24, which indicates that interior lighting contribution to the building EUI was 17% and 13% due to automated on/off and continuous dimming sensors, respectively.

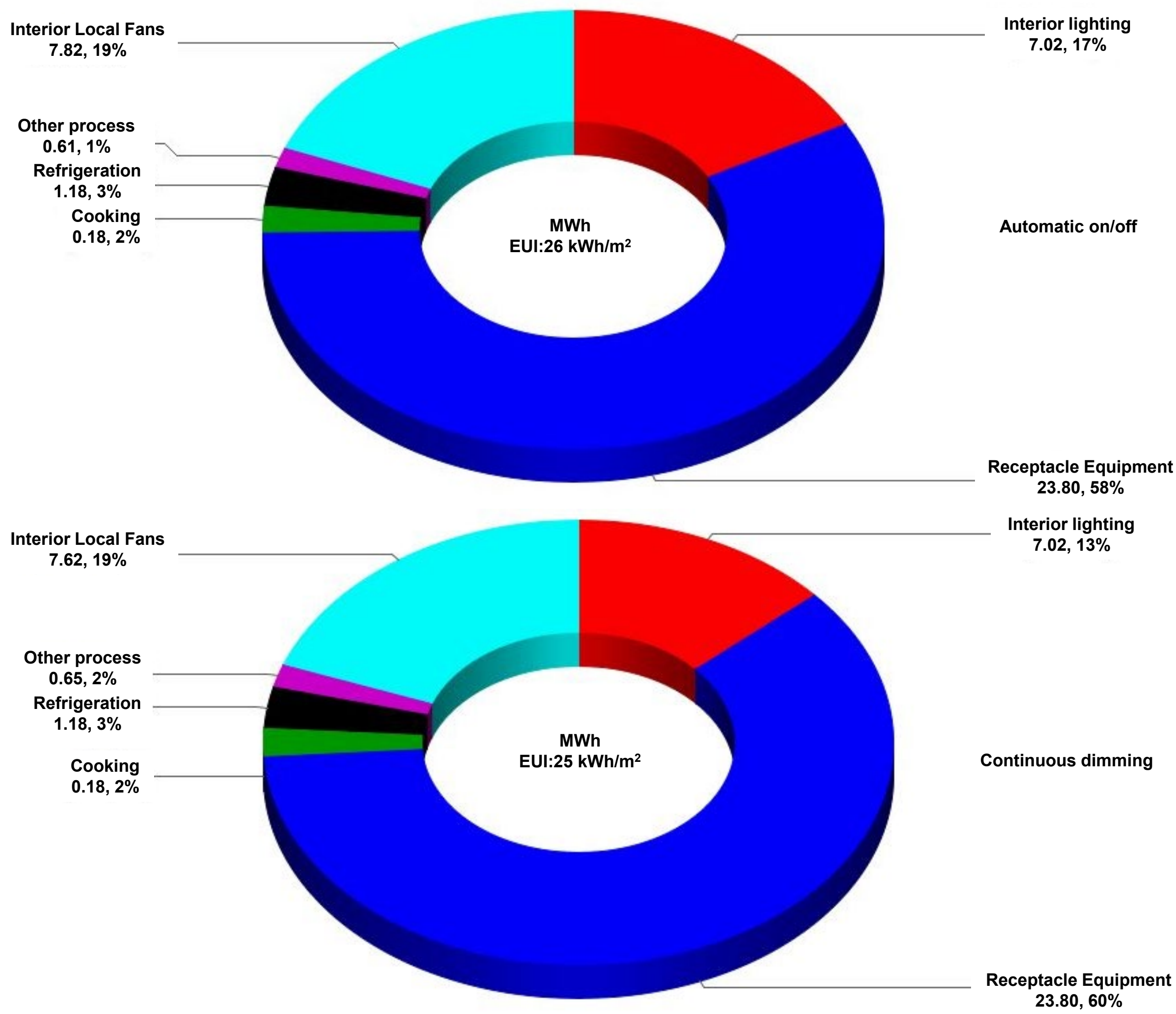


Figure 5.24: The building overall energy-use intensity due to automatic on/off and continuous dimming daylight-linked control sensors

The use of automated on/off sensors reduced the interior lighting annual cumulative energy from 14.64 MWh to 7.02 MWh, while continuous dimming sensors reduced overall consumption to 5.31 MWh. The overall EUI of the building was reduced to 26 kWh/m^2 using automated on/off sensors and was further reduced by 1 kWh/m^2 using continuous dimming sensors.

In terms of the energy costs and benefits, the same tariff structure and procedure used to deduce the building's "as-is" energy cost in Chapter 4 was employed to compute the building optimised lighting energy cost. The building's monthly "as-is" and optimised energy costs are presented in Figure 5.25.

In Figure 5.25, the optimised lighting energy cost was 49% less than the "as-is" lighting energy cost due to automated on/off sensors and 60% less due to continuous dimming sensors. The average summer lighting energy cost due to automated on/off sensors was R650.81 per month and R486.00 per month due to continuous dimming sensors. Hence, the optimised automated on/off lighting energy cost in summer is 55% less than the "as-is" lighting energy cost, while continuous dimming lighting energy cost is 60% less.

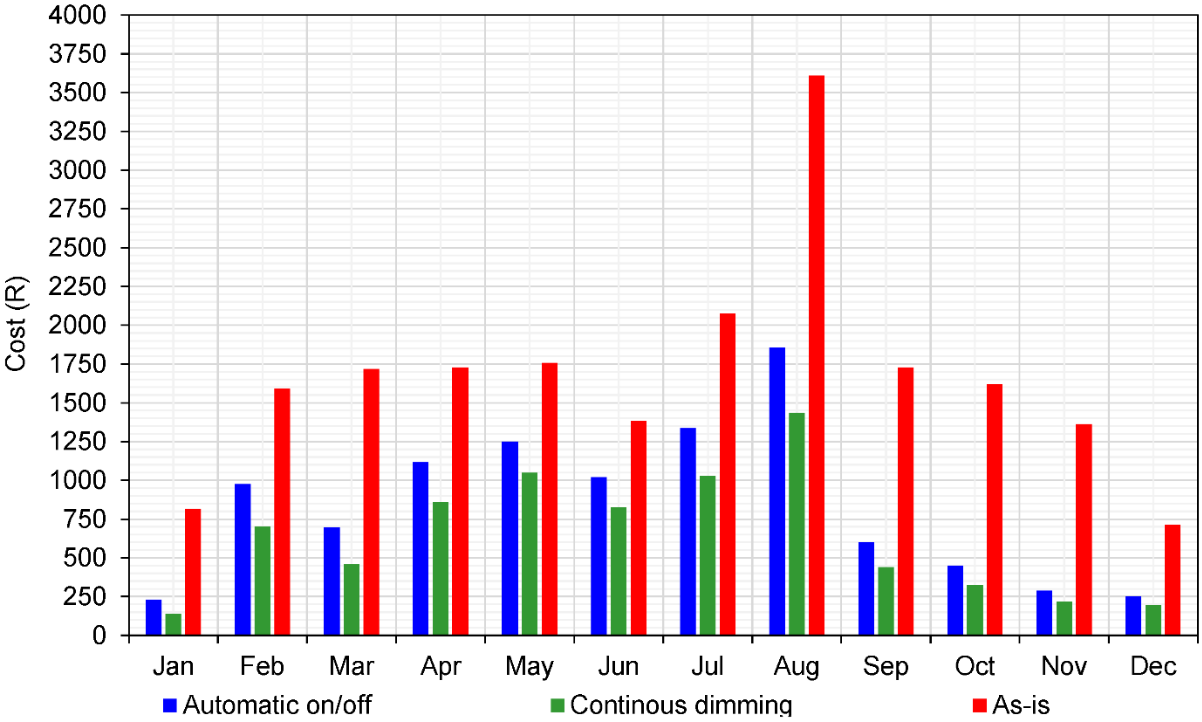


Figure 5.25: Monthly "as-is" and optimised lighting energy cost of the building

However, a higher optimised lighting energy cost was observed using both sensors in winter, implying lower energy cost savings. The winter low energy cost savings is due to the fewer winter months and the holidays that were factored in the annual building schedules (refer to Table 5-5). Moreover, in winter, automated on/off and continuous dimming lighting average energy costs were R1 403.58 and R1 096.04, thus equivalent to 40% and 53% energy cost savings, respectively.

In addition to the building optimised energy cost benefits evaluation, environmental mitigation was also assessed. Figure 5.26 shows the mitigated CO_2 emissions due to the optimised lighting energy alongside the "as-is" CO_2 emissions.

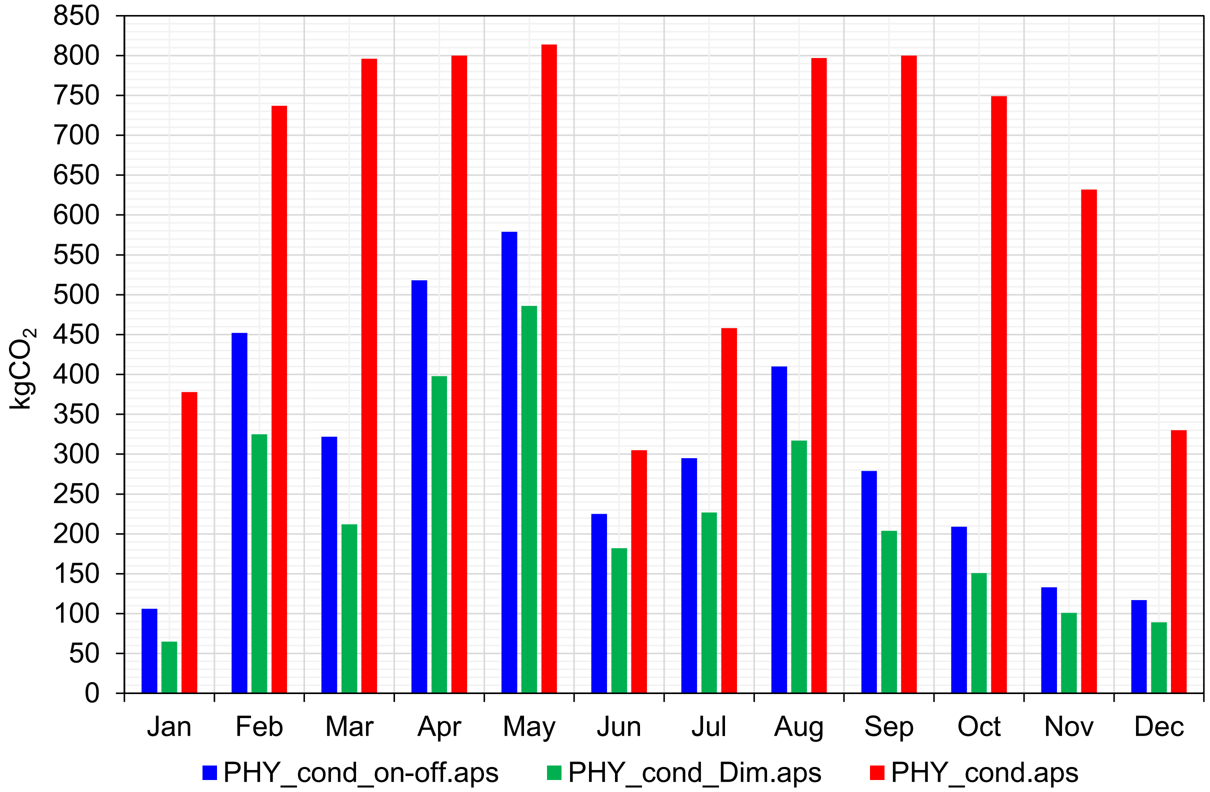


Figure 5.26: The building optimised lighting energy environmental mitigation

Figure 5.26 shows that automated on/off and continuous dimming sensors resulted in 52% and 64% CO_2 mitigation, respectively. The automated on/off lighting energy consumption was equivalent to 3 644 kg per annum CO_2 emissions, while continuous dimming lighting energy consumption was equivalent to 2 727 kg per annum CO_2 emission. Overall, automated on/off intervention reduced the whole-building CO_2 emission by 16% and 19% with continuous dimming interventions.

5.5 Conclusions

The simulation-based analyses of the building revealed the impact of the adjacent structure on the distribution of daylight for indoor spaces. The impact was observed on the luminance and illuminance of the affected east and west-facing spaces. The "as-is" energy performance simulation for the entire building reveals that receptacle equipment accounts for the highest energy consumption at 49%, while electric light was the second-highest energy consumer at 30%. The simulated energy-use intensity of the building was 31 kWh/m^2. Receptacle equipment and lighting exhibit a similar trend in terms of simulated energy cost, with receptacle equipment accruing R32 702.14 per year while lighting energy amounted to R20 091.86 per year. The overall building energy cost was R67 108.50 per annum, which averages to

R5 592.31 per month and R43.00/m^2. CO_2 emission for total lights was 7 596 kg per annum, but total equipment had the highest emissions at 13 942 kg per annum. System CO_2 emission was the lowest at 4 201 kg per annum. The overall annual emission for the building is 25 440 kg which averages to 2 120 kg per month.

Data and analyses indicate that the use of automated on/off sensors in the building could reduce lighting energy demand for summer weekdays by 1.33 kW and winter weekdays lighting demand by 1.84 kW. This demand reduction is equivalent to 47% and 26% on summer and winter weekdays, respectively. The reduction in lighting energy demand resulted in 52% of lighting energy savings and 16% of whole-building energy and energy-use intensity (EUI) reductions. The energy cost benefits of automated on/off intervention were found to be 50% per annum, i.e. the “as-is” lighting energy cost was reduced from R20 091.89 per annum to R10 068.11 per annum. The environmental impact of the building lighting and whole-building energy consumption was mitigated by 52% and 16%, respectively.

In terms of the use of continuous dimming sensors as daylighting intervention, summer and winter weekdays' average lighting demand was reduced by 0.86 kW and 1.50 kW, respectively. This is equivalent to a 65% lighting demand reduction in summer and 58% in winter. The resultant lighting annual energy savings is 9.32 MWh, which is equal to 64%, while the whole-building demand and EUI were reduced by approximately 20%. Continuous dimming sensors were found to reduce the lighting energy cost by 62%, thus saving R12 420.73 per year. Mitigation of CO_2 emissions due to the lighting annual energy usage and the whole-building energy consumption were reduced by 64% and 19%, respectively.

The findings systematically demonstrate that continuous dimming daylight-linked is the most feasible daylight intervention. The findings also show that daylighting can be used to optimise the building's energy performance. Most importantly, the findings strongly demonstrate that the lights should be controlled with daylight-linked sensors in order to achieve the best optimisation in energy performance. However, this also requires the effective operation of window covers through the choice of appropriate blinds and curtains.

CHAPTER 6

Consolidation of Sub-findings, Conclusions and Recommendations

6.1 Introduction

This study evaluates options in daylighting interventions for a heritage instruction-cum-office building with the objective of reducing overall energy-use intensity (EUI), related operational energy cost and mitigation of CO_2 emissions. The study demonstrates the potential of heritage buildings to utilise daylight for energy efficiency without altering the original structure. The purpose of the study was also to show how buildings completed before 1999 can be considered for energy efficiency initiatives in South Africa in contrast to Energy Performance Certificate (EPC) regulations that currently exclude such buildings from the EPC initiative for the time being.

The study hypothesised that heritage buildings could utilise daylighting to save up to 50% on lighting energy usage and resultant operational cost and mitigate CO_2 emissions using non-invasive daylight interventions. Guided by four sub-questions, the study derived related sub-findings which are consolidated in this Chapter in order to derive overall findings on the main research question. The first sub-question focused on the status quo (as-is) EUI for the selected case study building, while the second one focused on key daylighting interventions for the case study building. The third sub-question addressed the "as-is" contribution of daylighting to the EUI of the building, and the final one focused on feasible retrofits for daylighting interventions toward reducing EUI as well as the related viability of such interventions. Sub-findings on the sub-questions were derived from analyses of primary and secondary data. Primary data were mainly generated by experimental and simulation assessments of the building's daylighting and energy performance. This Chapter covers the consolidation of the sub-findings into the overall findings of the study, as well as overall conclusions and recommendations for further studies.

6.2 The "as-is" Energy-use Intensity of the Building

Sub-question one was addressed through whole-building energy performance simulation as covered in Chapter 4. Secondary data on floor area, the building thermal component dimensions, and optical properties were used to develop the building model. The primary data on the number of lights and appliances in the various spaces of the building were also collected. Secondary data consists of the nameplate power rating of the lights and appliances as well as the occupancy period for the spaces. Occupancy periods of spaces relative to the dominant uses of the building were obtained from the 2018 prospectus of the Faculty of Science and Agriculture at the University of Fort Hare. This was to ensure that the normal academic schedule of the building was used as opposed to its use schedule during the Covid-19 pandemic period. Secondary and primary data were used to schedule annual operations for lighting and appliances as one of the key inputs for the “as-is” and optimised lighting energy performance simulation for the building.

From the simulation, the whole-building annual energy consumption was derived to be 49.02 MWh. Receptacle equipment was the highest energy consumer at 23.8 MWh per annum, while lighting had the second-highest consumption at 14.64 MWh per annum. “As-is” EUI was derived to be 31 kWh/m^2/yr at a resultant operational energy cost of R67 108.50 per annum. In terms of environmental impact, the building’s annual energy consumption is equivalent to 25 440 kg CO_2 emissions.

6.3 The Building Key Daylighting Interventions

From the walk-through audit, no specific daylighting interventions for the building were found. The audit established that the building has a conventional design with external side-lighting (vertical windows) that admit natural lights and ventilation at the same time. However, the majority of the windows have vertical fabric blinds, while one of the spaces had venetian aluminium blinds. Spaces with vertical fabric blinds were found to have better daylight illuminance than the space with venetian aluminium blinds. Nevertheless, the building daylight simulation (which excluded window covers) revealed that the indoor average daylight illuminance of the ground floor spaces ranges between a high of 6 347.02 lux and a low of 23.01 lux, while the top floor spaces' average illuminance ranges from a low of 38.37 lux to a high of 6 411.59 lux.

Building orientation relative to the daily sun trajectory and adjacent structure is the most critical factor influencing the irregular indoor daylight distribution of the building. Based on the findings, and with secondary data from Atif and Galasiu (2003), Lim *et al.* (2017), and Yu *et al.* (2015), automated on/off and continuous dimming daylight-linked sensors were identified and used as daylighting-related interventions in the building. Automated on/off daylight-linked sensor controls electric lights based on a pre-set ambient light level. The sensor automatically switches off electric lights when the pre-set ambient light level is met and switches on the lights when the indoor illuminance is below the pre-set ambient light level. Continuous dimming daylight-linked sensor also controls electric lights using ambient light level by gradually decreasing the power demand of electric lights as the indoor illuminance increases and vice versa.

6.4 "As-is" Daylighting Contribution to the Building Energy-use Intensity

Sub-question 3 deals with the energy savings due to the building's "as-is" daylighting. As indicated in Section 6.2, no daylighting retrofit interventions were evident in the building during the walk-through audit. However, the experimental aspect of the research targeted the potential lighting energy savings if daylight-linked sensors were installed in the building to control electric lights. Unlike the simulation evaluation of the lighting performance of the building, the experimental evaluation included the effect of the window covers such that the measured daylight illuminance is the "as-is" operating conditions for the respective spaces where measurements were taken (due to the limited number of sensors only six spaces out of 33 conditioned spaces and 68 including unconditioned spaces were sampled for the experiment-based component of the study).

The experiment-based component also entailed an onset HOBO photometric sensor placed on the desk in each sampled space to monitor the daylight illuminance sensed by an occupant sitting at the desk. The experiment was conducted from April to July, with April and May representing summer while June and July represented winter. Experimental data revealed that the average daylight illuminance of three of the spaces sampled was below the South African workplace light threshold of 300 lux, while the average illuminance of the other three spaces was above the 300 lux threshold. This implies that only the spaces with average daylight illuminance above 300 lux can utilise daylight-linked sensors for lighting energy efficiency. In the winter season, spaces with daylight illuminance above 300 lux were found to have the potential of 1.61 kWh lighting energy savings on weekdays, approximately 15% savings. On weekends, the lighting energy savings were up to 52%. Summer lighting energy was observed to be the least, with a maximum savings of 33% on weekdays and 24% on weekends. The resultant lighting energy cost savings for the six spaces were 57% in summer and 25% in winter.

6.5 Feasible Daylighting Interventions for Energy-use Reduction

As indicated in Section 6.2, automated on/off and continuous dimming daylight interventions were simulated towards optimisation of lighting energy performance and resultant EUI of the building. Sub-question 4 was addressed using simulation, and thus the primary and secondary data in section 6.1 were used in developing the building model. For purposes of the simulation, both sensor-types were modelled facing downward from the ceiling and executed sequentially.

Continuous dimming daylight intervention resulted in more energy savings than automated on/off daylight intervention. Continuous dimming sensors reduced the annual energy-use for lighting by 64% and overall annual energy-use by 20%, while overall EUI was reduced by 19%. The resultant overall energy cost saving was R12 420.73 per annum, while the mitigated CO_2 emission was 4 839 kg per annum.

6.6 Consolidation of Findings and Conclusions

From the findings, the study hypothesis that heritage buildings can utilise daylighting for up to 50% lighting energy savings and resultant operational cost and CO_2 emissions is provisionally validated, bearing in mind the simulated results of the study. As illustrated in Chapter 4, three out of six spaces sampled have sufficient daylight illuminance for typical office tasks based on the South African workplace light level recommendation. The spaces were found to have the potential to optimise daylight utilisation to save up to 33% lighting energy in summer and 52% in winter. The resultant energy cost-benefit was up to 57% in summer and 25% in winter. A graphic summary of the experimental findings of the research is presented in Figures 6.1 and 6.2.

Figure 6.1: Daylighting performance summary of selected spaces on the building's ground floor

However, the whole-building daylighting simulation revealed that the maximum illuminance of the building is 16 411.54 lux. The relatively high indoor daylight illuminance is due to the exclusion of the window covers in the simulation. This implies that a significant amount of daylight can be harvested in the building with an effective operation of the window covers and choice of window cover materials. Opening the windows during the day or using dynamic photosensors to operate the windows would result in significant improvements in daylight illuminance indoors.

Figure 6.2: Daylighting performance summary of selected spaces on the building's top floor

Moreover, simulation for optimised lighting energy performance, as reported in Chapter 5, shows that using automated on/off sensors reduced the annual lighting energy by 7.61 MWh (52% energy savings) and 9.32 MWh (64% energy savings) due to continuous dimming. Similarly, automated on/off sensors reduced the whole-building annual energy consumption and EUI by 7.77 MWh and 5.0 kWh/m^2/yr, respectively, which is equivalent to a 16% reduction in each case. In terms of continuous dimming, the whole-building annual energy was reduced by 9.4 MWh (20% savings), while the EUI was reduced by 6.0 kWh/m^2/yr (19% reduction). Lighting and energy performance simulation further ascertain the potential of utilising daylight for lighting and whole-building energy savings. Lighting interventions also reduced operational energy costs and mitigated CO_2 emissions. The use of automated on/off sensors reduced the lighting energy cost by 50%, and a 62% reduction was observed for continuous dimming sensors. Further, CO_2 emissions due to annual lighting energy consumption were mitigated by 52% and 64% using automated on/off and continuous dimming sensors, respectively.

Automated on/off sensors reduced annual CO_2 emissions for the entire building by 16% and 19% for continuous dimming sensors.

6.7 Limitations and Recommendations

The experimental evaluation of the building, which captured the building's daylight performance at operating conditions, was limited to six spaces (offices) due to limited photometric sensors. The experimental observation was also limited to the daylight falling on the desk in the respective spaces. The spot measurement adopted in the experimental approach was insufficient to quantify the distribution and the amount of daylight in the entire space compared to the experimental and simulation findings. Although the simulation approach covered the daylighting distribution in a given space and the entire building, it was limited to design conditions. In other words, human interference, such as the choice of window covers, operation of windows covers and electric lights, were not considered. Also, the optical properties of the windows in the model were based on the existing database in the IES application, which may vary from the building's actual windows. Further, the experimental and simulation findings are limited to Alice's weather conditions since the research was conducted in Alice only. Occupants' perception of the indoor daylight level is another crucial aspect regarding the use of daylight for lighting energy efficiency that was not considered in both approaches of the research.

Regarding the building energy performance evaluation, the lights' operation in the experimental approach was based on measured illuminance data, while the simulated light operation was based on classes schedule. In addition, the power factor and lamp decay factor were not considered in the lighting energy computation. The computed lighting energy was based on active power.

In view of the outlined limitations, the use of multiple photometric sensors for the experimental evaluation of daylight is recommended. As alluded to by Kruisselbrink, Dangol and Rosemann (2018), photometric sensors in daylight evaluation should be set up in a grid that covers at least the area of interest in the space. Figure 6.3 shows a schematic diagram of the daylight evaluation experimental approach.

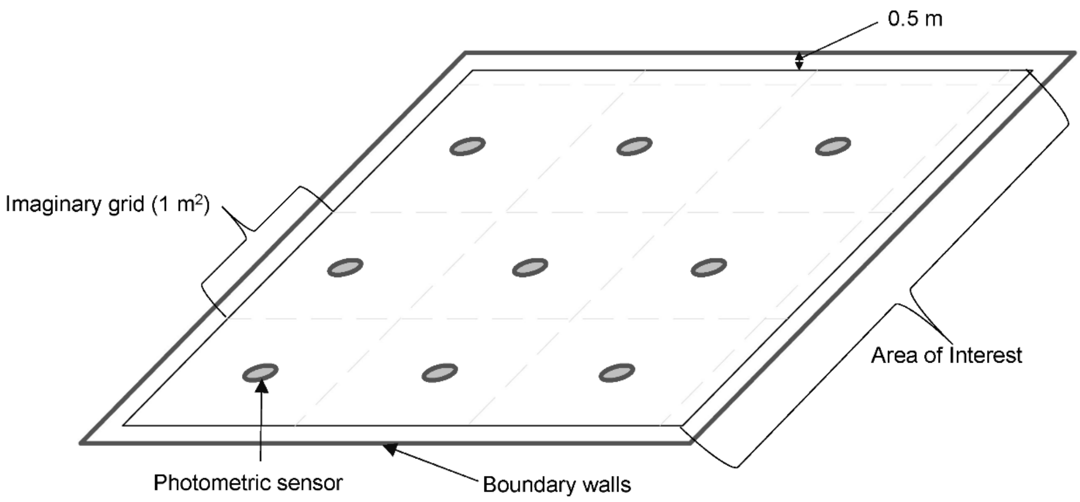


Figure 6.3: Experimental daylight evaluation approach

However, this approach increases the cost and time of the research, thus, the simulation approach is a cost and time mitigating method for whole-building daylight experimental evaluation (Yu *et al*., 2015). Moreover, it is recommended that window covers be integrated into building modelling to simulate daylighting performance with the effect of blinds to demonstrate daylight performance under operating conditions. The feasibility of adopting daylight for lighting energy savings in other heritage buildings in South Africa is a study that should be considered in the future. Such studies would create a benchmark for energy performances and lighting energy efficiency regulation of heritage buildings in the country. Further, occupants' perception of daylight level needs to be considered in future studies as it can be used to reduce workplace light requirement threshold, which will result in an increase in the lighting energy saving and overall energy EUI. Arising from the delineation (Chapter 1, Section 1.10), further study on allowable fenestration changes and related simulation for daylight performance should be undertaken to assess the extent to which fixed fenestration influences indoor daylight optimisation.

Furthermore, by comparison of experimental and simulation findings, the use of continuous dimming sensors and effective operation of window covers would result in energy savings in commercial buildings regardless of age. Modern designs incorporate dynamic photosensors in buildings to aid the operation of window covers based on outdoor and indoor illuminances. The use of non-invasive dynamic (photo-automated) window covers in heritage buildings would therefore result in enhanced indoor daylighting and, at the same time, reduce glare and visual discomfort by preventing an excessive amount of sunlight penetration. In addition, as observed in Chapter 4, window cover materials with low transmissivities, such as aluminium blinds, are likely to result in poor indoor daylighting levels as well as low uniformity in distribution.

However, the choice of window cover materials should be influenced by the dominant task lighting requirement for the space. Further, a side-lighting design strategy where the same windows are used for daylighting and ventilation is one of the setbacks of daylighting in heritage buildings. As indicated in Chapter 4, side-lighting is commonly associated with poor indoor daylight quality due to low uniformity and diversity, which in turn results in visual discomfort for many occupants. Building orientation, adjacent structures, and indoor furniture are the main influencing factors of the quality of light in side-lighting design strategies. Therefore, effective daylighting in heritage buildings with side-lighting is a factor of the distance of the area of interest from the external windows as shown in the building's annual sunlight exposure in Figure 6.4.

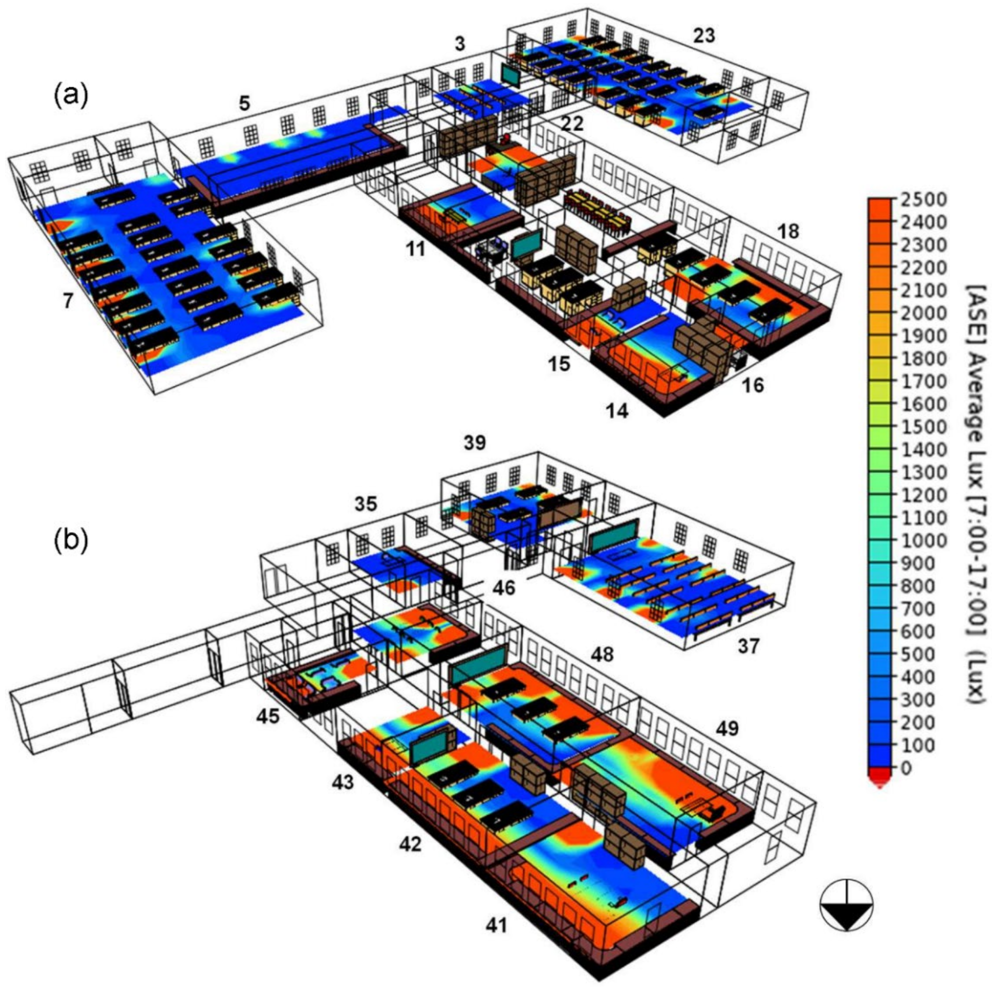


Figure 6.4: Annual sunlight exposure of the building; (a) top floor and (b) ground floor

A way of addressing this challenge without altering the structure would be through repurposing floor areas by placing tasks with high light level requirements in spaces with larger window areas, closer to the building perimeter, and east, north or west facing depending on the dominant task period. The occupants sitting or working position with respect to the direction of direct sun rays should be taken into consideration to avoid glare.

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Appendix A-1: Inventory of ground floor lights and appliances

Space	Activity	Type of light	Quantity per bulb/tube	Rating (W)	Total power (W)	Type of appliances	Quantity	Rating (W)	Total power (W)
33	Foyer	CFL	2	16	32				
34	Storage	Magnetic FT T8	2	20	40				
35	Single-office	Magnetic FT T8	4	20	80	Desktop computer	1	200	200
						Printer	1	65	65
						Telephone set	1	15	15
						Electric kettle	1	3000	3000
36	Lecture hall	Magnetic FT T8	12	20	240	Projector	1	300	300
37	Lecture hall	Magnetic FT T8	20	20	400	Projector	1	300	300
						Air conditioner (split unit)	2	2300	4600
38	Storage	Magnetic FT T8	2	20	40				
39	Laboratory	Magnetic FT T8	24	20	480	Lab apparatus	20	5	100
40	Office hallway	Magnetic FT T8	6	20	120				
41	Singl-office	Electronic FT T5	12	35	420	Desktop computer	1	200	200
						Speaker	1	35	35
						Telephone set	1	15	15
						Standing fan	1	50	50
42	Laboratory	Magnetic T8	12	20	240	Lab apparatus	10	8	80
43	Single-office	Electronic FT T5	4	35	140	Desktop computer	1	200	200
						Printer	1	65	65
						Laptop computer	1	65	65
						Electric heater	1	1900	1900
						Telephone set	1	15	15
						Electric kettle	1	2200	2200
44	Single-office	Electronic FT T5	4	35	140	Electric kettle	1	2000	2000
						Standing fan	1	50	50
						Electric heater	1	2500	2500
						Laptop computer	4	65	260
45	Single-office	Electronic FT T5	4	35	140	Standing fan	1	50	50
						Electric heater	1	2500	2500
						Laptop computer	3	65	195
						Desktop computer	2	200	400
46	Laboratory	LED	6	12	72	Laptop computer	3	65	195
47	Cleaner sitting area	Incandescent bulb	4	60	240	Electric kettle	1	2000	2000
						Electric heater	1	2500	2500
48	MSc students shared-office	Electronic FT T5	16	35	560	Laptop computer	4	65	260
						Desktop computer	3	200	600
						Electric heater	1	2000	2000
49	Single-office	Electronic FT T5	12	35	420	Desktop computer	1	200	200
						Speaker	1	35	35
						Telephone set	1	15	15
						Standing fan	1	50	50
						Electric heater	1	2500	2500
50	Storage	Electronic FT T5	2	35	70				
53	Bathroom	Magnetic FT T8	1	20	20				
		Incandescent bulb	2	60	120				
54	Entrance hallway	Magnetic FT T8	6	20	120				

Appendix A-2: Inventory of top floor lights and appliances

Space	Activity	Type of light	Quantity per bulb/tube	Rating (W)	Total power (W)	Type of appliances	Quantity	Rating (W)	Total power (W)
0	Single-office	Electronic FT T5	2	35	70	Desktop computer	1	200	200
					0	Printer	1	65	65
1	Storage	Electronic FT T5	2	35	70				0
2	Storage	Electronic FT T5	4	35	140				0
3	Lecture hall	Electronic FT T5	4	35	140	Projector	1	300	300
		Magnetic FT T8	8	20	160				0
4	Single-office	Magnetic FT T8	4	20	80	Laptop computer	1	65	65
						Printer	1	65	65
						Telephone set	1	15	15
						Speaker	1	35	35
						Desktop computer	1	200	200
5	Laboratory	Magnetic FT T8	14	20	280	Lab apparatus	10	5	50
6	Foyer	Magnetic FT T8	2	20	40				0
7	Laboratory	Magnetic FT T8	24	20	480	Lab apparatus	20	5	100
8	Entrance hallway	Magnetic FT T8	14	20	280				0
9	Bathroom	CFL	3	12	36	Hand dryer	1	2500	2500
10	Cleaner sitting area	Electronic FT T5	4	35	140	Electric heater	1	1200	1200
11	Single-office	Electronic FT T5	4	35	140	Telephone set	1	15	15
						Desktop computer	1	200	200
						Standing fan	1	60	60
12	Single-office	Magnetic FT T8	2	20	40	Telephone set	1	15	15
		Electronic FT T5	2	35	70	Laptop computer	1	65	65
					0	Electric heater	1	2000	2000
13	Laboratory	Magnetic FT T8	8	20	160	Lab apparatus			0
14	Single-office	Electronic FT T5	6	35	210	Desktop computer	1	200	200
						Electric heater	1	1500	1500
						Telephone set	1	15	15
						Electric kettle	1	1400	1400
15	Single-office	Electronic FT T5	4	35	140	Desktop computer	1	200	200
						Printer	1	65	65
						Telephone set	1	15	15
						Speaker	1	35	35
16	Single-office	Electronic FT T5	2	35	70	Desktop computer	1	200	200
						Standing fan	1	60	60
						Electric kettle	1	1500	1500
17	Office hallway	Magnetic FT T8	4	20	80				0
18	Laboratory	Magnetic FT T8	4	20	80	Desktop computer	4	200	800
		CFL	4	12	48				0
19	Laboratory	Magnetic FT T8	4	20	80	Desktop computer	3	200	600
					0	Electric heater	1	2500	2500
20	Boardroom	Magnetic FT T8	8	20	160	Refrigerator	1	180	180
					0	Printer	1	65	65
21	Single-office	Electronic FT T5	4	35	140	Desktop computer	1	200	200
						Printer	1	65	65
						Laptop computer	1	65	65
						Telephone set	1	15	15
22	Single-office	Electronic FT T5	4	35	140	Telephone set	1	15	15
						Desktop computer	1	200	200
						Laptop computer	1	65	65
						Air condition	1	2300	2300
						Electric kettle	1	1500	1500
23	Laboratory	Magnetic FT T8	24	20	480	Lab apparatus	10	5	50
24	Storage	Electronic FT T5	2	35	70				0
25	Storage	Electronic FT T5	4	35	140				0

Appendix B-1: Ground floor spaces solar shading

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	11.0	77.6	94.2	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	0.0	44.0	99.7	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	19.8	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	-0.0						
Apr							0.0	0.0	60.1	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	29.6	100.0	100.0	100.0	53.5	0.0	0.0	0.0	0.0							
Jun								0.0	2.9	84.7	100.0	100.0	88.1	0.0	0.0	0.0	0.0							
Jul								0.0	4.3	85.4	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	39.2	100.0	100.0	100.0	44.7	0.0	0.0	0.0	0.0							
Sep							0.0	20.7	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	0.0	74.4	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						0.0	28.1	87.4	99.7	100.0	100.0	36.6	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						0.0	27.8	81.2	95.0	100.0	100.0	80.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.2	80.6	75.3	69.1	63.6	73.5	81.6					
Feb						0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.4	84.8	78.1	74.5	71.0	79.5	86.3					
Mar							0.0	0.0	0.0	0.0	0.0	0.0	25.6	89.9	81.8	79.0	82.2	88.2						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	38.9	96.4	91.0	89.0	90.7							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.4	96.9	97.9	97.5							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	100.0	98.7	99.3	99.3							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	100.0	98.2	98.6	98.6							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	98.7	94.3	93.8	94.0							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	100.0	90.8	84.3	81.2	86.6							
Oct						0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.2	82.2	78.1	74.1	79.6	85.1						
Nov						0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.2	79.0	74.1	67.5	69.3	79.1						
Dec						0.0	0.0	0.0	0.0	0.0	0.0	0.0	89.0	78.9	73.3	66.1	62.4	74.2	81.7					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	4.5	3.4	2.2	1.3	0.5	0.4	1.2	1.7	2.6	4.3	7.9	0.0					
Feb						0.0	0.0	4.3	4.2	2.7	1.6	0.7	0.0	1.2	2.0	2.7	4.7	9.4	0.0					
Mar							0.0	0.0	5.0	3.2	1.9	0.9	0.0	1.2	2.6	4.1	6.7	0.7						
Apr							0.0	0.0	5.5	3.8	2.3	1.1	0.0	1.4	2.9	5.1	6.2							
May							0.0	0.0	0.6	4.4	2.6	1.2	0.0	1.3	2.8	4.5	0.0							
Jun								0.0	0.0	4.6	2.8	1.4	0.2	1.1	2.5	3.3	0.0							
Jul								0.0	0.0	4.8	2.9	1.5	0.3	1.0	2.5	4.0	0.0							
Aug							0.0	0.0	2.5	4.3	2.6	1.3	0.0	1.2	2.7	4.8	3.8							
Sep							0.0	0.0	5.0	3.1	1.8	0.8	0.3	1.5	3.2	5.5	10.0							
Oct						0.0	0.0	5.6	3.6	2.3	1.3	0.3	0.6	1.7	2.5	3.7	7.6	0.0						
Nov						0.0	1.5	4.5	3.0	1.9	1.0	0.0	0.7	1.5	2.0	3.3	5.7	8.9						
Dec						0.0	1.6	4.2	3.0	1.9	1.1	0.3	0.6	1.3	1.8	2.8	4.5	8.6	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	61.0	49.0	65.8	100.0	100.0	100.0	0.0	0.0	0.0	-0.0	0.0	0.0	0.0					
Feb						0.0	19.6	34.3	31.1	100.0	100.0	100.0	0.0	0.0	0.0	-0.0	-0.0	0.0	0.0					
Mar							0.0	15.2	0.0	62.9	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	0.0	0.0	32.2	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	14.7	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	11.6	91.2	100.0	100.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	9.0	86.6	100.0	100.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	2.3	100.0	100.0	100.0	0.0	0.0	-0.0	0.0							
Sep							0.0	0.0	0.0	70.3	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
Oct						5.0	25.1	19.4	39.1	100.0	100.0	100.0	0.0	0.0	0.0	-0.0	0.0	0.0						
Nov						11.5	55.4	40.0	89.4	100.0	100.0	100.0	0.0	0.0	0.0	-0.0	0.0	0.0						
Dec						10.9	67.0	51.0	94.3	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	91.2	91.2	88.3	80.8	71.7	59.1	41.5	22.7	0.0					
Feb						0.0	0.0	0.0	0.0	91.2	91.2	91.2	89.7	81.7	72.0	58.7	39.2	0.0	0.0					
Mar							0.0	0.0	34.3	89.5	91.2	91.2	90.3	82.3	73.4	62.1	49.7	0.0						
Apr							0.0	0.0	7.7	83.3	91.2	91.2	90.7	83.5	75.9	66.8	21.9							
May							0.0	0.0	33.1	91.2	91.2	91.2	91.2	84.9	78.2	70.7	0.0							
Jun								0.0	24.1	86.6	91.2	91.2	91.2	86.2	80.0	73.2	0.0							
Jul								0.0	21.1	87.0	91.2	91.2	91.2	86.4	80.1	73.1	0.0							
Aug							0.0	0.0	0.2	90.0	91.2	91.2	91.2	84.8	77.7	69.6	9.0							
Sep							0.0	0.0	35.6	90.1	91.2	91.2	89.0	81.3	72.6	61.7	36.0							
Oct						0.0	0.0	0.0	81.0	91.2	91.2	91.2	86.2	77.5	66.7	53.3	3.7	0.0						
Nov						0.0	0.0	0.0	0.0	91.2	91.2	91.2	85.6	77.4	66.9	52.4	32.0	0.0						
Dec						0.0	0.0	0.0	0.0	0.0	91.2	91.2	86.6	79.0	69.6	56.6	38.4	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	22.6	12.0	13.6	10.4	6.3	2.7	0.6	0.8	0.8	0.7	0.0	0.0	0.0					
Feb						0.0	0.0	10.1	2.5	12.9	8.2	4.2	1.0	1.2	1.3	1.2	0.0	0.0	0.0					
Mar							0.0	2.9	0.0	15.7	9.9	5.3	1.6	1.9	2.1	1.6	0.0	0.0						
Apr							0.0	0.0	0.0	5.4	11.4	6.5	2.6	2.9	3.5	1.5	0.0							
May							0.0	0.0	0.0	4.6	13.0	8.0	3.7	4.2	4.9	0.6	0.0							
Jun								0.0	0.0	6.4	14.5	9.2	4.9	4.9	5.8	0.2	0.0							
Jul								0.0	0.0	3.9	14.6	9.3	4.9	4.5	5.6	1.0	0.0							
Aug							0.0	0.0	0.0	2.1	12.6	7.6	3.2	3.4	4.1	1.6	0.0							
Sep							0.0	0.0	0.1	15.2	9.4	4.9	2.0	2.3	2.7	1.3	0.0							
Oct						0.0	10.4	4.3	8.1	11.4	6.8	2.7	1.3	1.5	1.7	0.3	0.0	0.0						
Nov						0.0	17.5	7.1	14.1	9.1	5.2	1.5	0.8	0.9	1.0	0.4	0.0	0.0						
Dec						0.0	21.7	10.4	13.9	9.0	5.1	1.6	0.6	0.7	0.7	0.5	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						86.9	79.9	82.2	99.6	45.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.1					
Feb						94.2	90.0	97.4	99.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							100.0	99.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							99.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.0							
Sep							99.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Oct						94.7	96.7	99.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						86.8	82.2	93.7	99.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.1						
Dec						81.6	74.8	79.9	99.0	48.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.8	62.1					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						34.4	34.4	34.4	34.4	34.4	20.4	24.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						34.4	34.4	34.4	34.4	29.4	21.8	18.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							34.4	34.4	25.7	17.8	13.7	8.8	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							9.1	13.8	5.8	2.9	1.4	0.5	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Aug							0.0	1.5	1.0	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0							
Sep							34.4	28.1	17.1	11.4	6.3	3.4	0.0	0.0	0.0	0.0	0.0							
Oct						34.4	34.4	34.4	30.1	21.3	17.4	14.4	0.0	0.0	0.0	0.0	0.0	-0.0						
Nov						34.4	34.4	34.4	34.4	31.4	25.0	6.2	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						34.4	34.4	34.4	34.4	34.4	30.1	19.6	0.0	0.0	0.0	0.0	0.0	0.0	-0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	-0.0	0.0	0.0	0.0	0.0	37.7	24.0	7.9	6.0	12.6	39.6	61.2					
Feb						0.0	0.0	-0.0	0.0	0.0	0.0	0.0	15.3	23.0	2.9	0.0	5.6	43.1	69.2					
Mar							0.0	-0.0	0.0	0.0	0.0	0.0	0.0	23.0	0.0	0.0	10.0	52.4						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	40.2							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	56.2							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.2	59.6							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	53.5							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	43.2							
Sep							-0.0	0.0	0.0	0.0	0.0	0.0	38.8	8.0	0.0	0.0	32.7							
Oct						0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.8	15.0	0.0	0.0	29.1	57.8						
Nov						0.0	-0.0	-0.0	0.0	0.0	0.0	0.0	30.4	19.7	1.5	7.0	21.5	50.6						
Dec						-0.0	0.0	-0.0	0.0	0.0	0.0	0.0	33.3	23.3	6.8	10.2	15.0	42.2	65.3					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						3.2	8.2	5.0	3.0	1.2	0.6	0.2	0.2	0.5	0.0	0.0	0.0	4.8	0.0					
Feb						0.0	8.7	5.1	2.6	1.4	0.8	0.2	0.0	0.3	0.0	0.0	0.0	6.9	0.0					
Mar							5.4	4.7	2.5	0.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.5						
Apr							0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5							
Sep							5.3	4.1	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1							
Oct						1.3	6.9	3.6	1.8	1.1	0.3	0.0	0.2	0.1	0.0	0.0	0.4	0.0						
Nov						8.7	6.9	4.0	2.1	1.0	0.5	0.0	0.3	0.3	0.0	0.0	0.5	9.2						
Dec						8.1	7.6	4.5	2.7	1.0	0.5	0.1	0.3	0.5	0.0	0.0	0.1	7.4	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	46.1	0.0	0.0					
Feb						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	36.0	0.0	0.0					
Mar							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	0.0	0.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	59.5	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	57.7	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	44.4	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	71.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	71.6	0.0							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	53.9	0.0							
Oct						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	69.3	0.0	0.0						
Nov						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	0.8	0.0						
Dec						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	36.6	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	4.2	7.8	12.8	13.4	0.0	0.0					
Feb						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	3.5	6.8	11.3	5.9	0.0	0.0					
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.1	6.3	10.9	0.0	0.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.9	5.7	5.3	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	3.9	2.4	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	1.7	2.4	0.0	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	1.8	3.0	0.4	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	5.1	5.4	0.0							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.8	3.6	7.0	8.8	0.0							
Oct						0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	4.7	8.3	13.8	0.0	0.0						
Nov						0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	5.4	9.4	15.6	0.0	0.0						
Dec						0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	4.9	8.7	14.1	8.8	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						100.0	100.0	100.0	99.9	99.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						100.0	100.0	99.9	99.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							100.0	99.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Sep							25.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Oct						100.0	100.0	99.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						100.0	100.0	99.9	99.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						100.0	100.0	100.0	99.9	99.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	1.8	2.5	1.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	0.1	1.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	0.6	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						0.0	2.0	1.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						0.0	2.6	2.5	1.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	56.3	27.3	44.8					
Feb						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	43.4	0.5	28.0					
Mar							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	90.8	91.3	19.8	0.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	100.0	94.7	57.6	37.4	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	70.5	20.2	14.5	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	71.2	3.5	4.5	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	89.4	7.6	11.9	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	91.3	41.9	29.4	0.0							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	100.0	99.5	79.0	54.6	0.0							
Oct						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	98.3	86.6	0.0	0.0						
Nov						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	35.6	31.5						
Dec						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	54.7	35.8	50.8					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	6.0	11.2	18.5	28.6	7.3	0.0					
Feb						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	5.2	10.5	18.0	19.5	0.0	0.0					
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.5	5.2	10.5	17.6	0.0	0.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	0.4	5.4	4.7	7.8	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.2	0.0	0.0	3.8	0.0	0.0	0.0							
Jul								0.0	0.0	0.0	0.2	0.0	0.0	3.9	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	1.3	0.8	0.0							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	1.3	6.3	9.2	17.2	0.0							
Oct						0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	7.6	13.9	23.7	0.0	0.0						
Nov						0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	7.9	13.7	22.6	3.0	0.2						
Dec						0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	7.2	12.6	20.6	25.2	7.3	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	2.5	88.5	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	0.0	43.8	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	13.0	97.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							5.4	23.6	95.3	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
May							46.8	8.2	89.9	87.3	100.0	100.0	99.6	0.0	0.0	0.0	0.0							
Jun								22.0	46.5	48.5	65.7	100.0	100.0	0.0	0.0	0.0	0.0							
Jul								23.4	64.9	65.6	75.0	100.0	100.0	0.0	0.0	0.0	0.0							
Aug							24.3	16.2	99.9	100.0	100.0	100.0	99.9	0.0	0.0	0.0	0.0							
Sep							0.0	39.8	99.2	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	0.0	63.4	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						0.0	33.9	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						0.0	37.1	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	17.1	14.1	9.3	5.4	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	0.0	13.0	17.2	11.2	6.8	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	0.0	20.7	13.1	7.4	3.2	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	5.8	21.0	12.2	6.9	3.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	17.3	10.5	6.1	2.8	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	3.2	0.4	5.6	2.6	0.3	0.0	0.0	0.0	0.0							
Jul								0.0	12.0	7.2	6.3	3.1	0.5	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	21.3	12.4	7.1	3.2	0.2	0.0	0.0	0.0	0.0							
Sep							0.0	4.9	20.1	11.7	6.3	2.4	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	0.0	23.4	15.0	9.6	5.2	1.3	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						0.0	3.8	17.8	12.5	8.0	4.2	0.7	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						0.0	3.8	15.6	12.4	8.0	4.4	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.3	51.9	98.5	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	0.0	36.2	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	7.2	95.4	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	0.0	49.1	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	26.5	100.0	100.0	100.0	99.7	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	77.7	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	75.4	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	34.7	100.0	100.0	100.0	99.9	0.0	0.0	0.0	0.0							
Sep							0.0	8.7	97.7	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	0.0	62.3	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						0.0	14.1	81.5	100.0	100.0	100.0	99.9	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						0.0	8.1	64.8	99.5	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	8.3	14.5	10.0	5.8	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	0.0	8.8	18.5	12.1	7.2	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	0.0	22.3	12.9	7.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	0.0	15.2	11.8	6.7	2.9	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.9	10.3	6.0	2.7	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	9.0	5.5	2.5	0.2	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	10.4	6.2	3.0	0.5	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	5.7	11.9	6.8	3.1	0.2	0.0	0.0	0.0	0.0							
Sep							0.0	0.0	19.7	11.0	6.1	2.4	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	0.0	24.9	16.2	10.0	5.1	1.3	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						0.0	0.0	15.8	13.5	8.6	4.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						0.0	0.0	9.0	12.9	8.6	4.7	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	82.7	55.8	32.8					
Feb						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	84.2	67.5	57.7					
Mar							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	63.5	50.1						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	60.8	1.1							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	26.4	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	100.0	88.7	12.2	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	100.0	95.0	31.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	49.9	0.0							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	80.3	30.8							
Oct						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	97.2	64.5	67.7						
Nov						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	71.0	53.9						
Dec						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	76.5	46.5	20.9					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	5.5	10.2	16.8	25.0	12.5	0.0					
Feb						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	4.8	9.6	16.3	26.5	10.1	0.0					
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.5	4.7	9.9	17.4	13.1	0.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	0.3	4.9	10.6	16.8	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	10.2	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	4.0	8.7	0.0	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	3.7	8.9	0.6	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	9.9	12.1	0.0							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	1.2	5.7	11.4	20.3	0.0							
Oct						0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	6.9	12.5	21.5	18.0	0.0						
Nov						0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	7.2	12.6	20.8	23.0	0.3						
Dec						0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	6.5	11.4	18.4	23.1	7.7	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	23.5	94.7	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	13.2	82.3	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							3.0	90.6	88.6	88.4	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							40.1	34.1	47.4	54.7	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
May							37.3	4.3	6.2	7.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	54.7	100.0	100.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	1.5	55.6	100.0	100.0	0.0	0.0	0.0	0.0							
Aug							51.8	17.6	28.3	24.9	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Sep							1.9	91.3	71.0	85.2	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
Oct						3.9	41.0	96.4	98.2	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						0.0	59.4	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						0.0	51.6	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	22.9	16.8	11.1	6.5	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	0.0	26.5	20.7	13.5	8.2	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	37.6	23.8	15.5	9.1	4.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	10.2	12.1	7.8	9.8	4.5	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	0.0	10.7	5.1	0.1	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	11.7	5.9	0.8	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	0.0	12.1	6.2	1.1	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	5.1	1.6	10.7	5.2	0.3	0.0	0.0	0.0	0.0							
Sep							0.0	37.9	17.4	14.4	8.3	3.3	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	14.9	28.1	18.1	11.5	6.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						0.0	15.7	21.6	15.0	9.6	5.1	0.9	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						0.0	12.3	20.2	14.8	9.6	5.3	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Appendix B-2: Top floor spaces solar shading

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						99.8	99.4	98.5	96.5	82.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						99.9	99.4	98.2	92.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							99.3	95.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							36.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Sep							98.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Oct						99.8	98.9	95.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						99.7	99.1	97.8	92.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						99.7	99.2	98.4	96.2	82.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.1	0.8	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						0.0	0.3	0.8	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						0.0	0.4	1.1	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						75.1	74.8	81.9	84.1	73.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.4					
Feb						68.7	64.6	77.6	78.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							39.2	67.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Sep							28.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Oct						58.8	65.9	77.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						71.4	76.4	82.7	81.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.4						
Dec						76.1	77.7	83.5	84.9	74.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	92.8	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						1.9	3.9	3.4	1.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	1.6	2.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	2.5	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						3.4	3.7	2.4	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2						
Dec						4.5	4.2	3.3	1.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	42.8	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	57.5	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	47.7	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Jun								30.3	97.7	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Jul								26.5	97.9	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Aug							0.0	43.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Sep							1.5	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	67.3	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						29.1	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						33.1	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	20.0	18.1	14.5	9.8	5.7	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	0.0	24.2	18.2	11.9	7.2	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	34.8	21.9	13.6	7.8	3.4	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	21.0	22.7	13.6	8.0	3.6	0.0	0.0	0.0	0.0	0.0							
May							0.0	2.0	22.8	13.8	8.1	3.8	0.1	0.0	0.0	0.0	0.0							
Jun								0.0	19.5	14.2	8.5	4.2	0.6	0.0	0.0	0.0	0.0							
Jul								0.0	20.8	14.9	9.0	4.6	0.8	0.0	0.0	0.0	0.0							
Aug							0.0	0.3	24.6	14.6	8.6	4.1	0.2	0.0	0.0	0.0	0.0							
Sep							0.0	35.1	20.9	12.3	6.9	2.7	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	24.0	24.5	15.9	10.1	5.4	1.4	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						0.0	22.2	17.9	13.2	8.4	4.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						0.0	19.4	16.1	12.8	8.5	4.6	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						100.0	100.0	100.0	99.9	94.3	82.6	42.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						100.0	100.0	100.0	100.0	97.2	88.4	62.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							100.0	100.0	100.0	99.2	91.8	69.8	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							100.0	100.0	100.0	100.0	94.7	76.9	0.0	0.0	0.0	0.0	0.0							
May							100.0	100.0	100.0	100.0	97.5	83.9	11.1	0.0	0.0	0.0	0.0							
Jun								100.0	100.0	100.0	99.4	89.1	12.9	0.0	0.0	0.0	0.0							
Jul								100.0	100.0	100.0	99.4	89.4	19.9	0.0	0.0	0.0	0.0							
Aug							100.0	100.0	100.0	100.0	96.8	83.0	9.3	0.0	0.0	0.0	0.0							
Sep							100.0	100.0	100.0	99.0	90.9	64.8	0.0	0.0	0.0	0.0	0.0							
Oct						100.0	100.0	100.0	100.0	94.9	82.1	19.8	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						100.0	100.0	100.0	98.5	91.7	74.8	1.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						100.0	100.0	100.0	98.4	91.7	76.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	48.5	56.1	58.7	58.6	42.0	0.0					
Feb						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.0	56.1	58.8	58.9	34.2	0.0					
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.0	57.1	58.9	59.0	15.4						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	7.5	50.3	58.5	59.0	30.7							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	51.5	59.0	59.0	6.4							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	50.4	59.0	58.6	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	48.6	59.0	59.0	7.7							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	49.2	58.5	59.0	25.9							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	9.7	51.6	58.5	59.0	38.0							
Oct						0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.6	52.9	58.4	58.9	51.1	7.8						
Nov						0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.3	52.5	57.8	58.7	58.7	24.6						
Dec						0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.1	50.8	56.8	58.6	58.3	35.9	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						8.3	9.2	5.8	3.9	2.5	1.5	0.2	0.0	0.7	1.3	2.2	3.7	7.1	0.0					
Feb						0.0	13.1	7.4	4.7	3.1	1.9	0.7	0.0	0.7	1.3	2.3	4.0	5.3	0.0					
Mar							12.6	9.5	5.7	3.6	2.2	1.0	0.0	0.7	1.5	2.7	5.3	0.0						
Apr							0.0	12.7	7.0	4.3	2.6	1.2	0.0	0.8	1.8	3.7	2.9							
May							0.0	14.8	8.8	5.2	3.1	1.5	0.0	0.9	2.1	5.0	0.0							
Jun								9.4	10.4	6.1	3.6	1.9	0.0	0.8	2.2	5.5	0.0							
Jul								9.9	10.5	6.1	3.7	1.9	0.0	0.7	2.0	4.7	0.0							
Aug							0.0	16.1	8.1	4.9	3.0	1.5	0.0	0.7	1.8	3.9	0.0							
Sep							12.9	9.4	5.6	3.6	2.1	0.7	0.0	0.9	1.8	3.4	7.0							
Oct						4.3	11.1	6.4	4.1	2.6	1.5	0.0	0.2	1.0	1.8	3.2	6.2	0.0						
Nov						13.0	8.2	5.2	3.4	2.2	1.2	0.0	0.3	1.0	1.7	2.8	4.8	0.0						
Dec						12.5	7.8	5.0	3.4	2.2	1.2	0.0	0.2	0.8	1.5	2.4	4.0	7.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						44.6	53.7	71.2	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						12.9	31.7	42.8	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							1.2	7.0	65.4	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	0.0	42.3	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	18.2	88.2	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	67.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	63.6	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	29.9	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Sep							0.0	7.8	67.3	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
Oct						17.6	11.5	50.3	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						57.7	54.6	91.3	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						75.3	67.6	97.2	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	11.7	24.0	17.9	11.7	6.9	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	3.0	4.2	21.9	14.3	8.6	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	0.0	26.3	16.3	9.4	4.1	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	0.0	9.8	16.3	9.4	4.2	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	15.8	9.3	4.3	0.1	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	12.6	9.4	4.6	0.6	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	13.2	10.1	5.1	0.9	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.6	17.1	9.9	4.7	0.3	0.0	0.0	0.0	0.0							
Sep							0.0	0.0	25.1	14.8	8.2	3.3	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	0.0	20.1	19.1	12.2	6.5	1.7	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						2.2	8.9	23.6	15.9	10.1	5.4	0.9	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						3.2	14.6	21.8	15.7	10.2	5.6	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						39.4	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						2.3	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							83.0	46.8	62.2	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							11.6	0.0	42.3	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	19.9	84.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	51.7	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	52.4	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	32.4	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0							
Sep							53.4	8.6	64.3	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
Oct						49.4	100.0	80.7	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						95.3	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						68.9	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	3.6	14.7	15.9	12.1	7.1	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	3.5	21.7	22.2	14.7	8.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							4.9	21.6	26.2	13.5	6.9	2.8	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	0.0	6.2	9.4	4.7	1.8	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	4.4	2.4	1.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.4	1.6	0.6	0.1	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	1.2	2.1	0.9	0.1	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	7.3	3.8	1.5	0.1	0.0	0.0	0.0	0.0							
Sep							6.7	0.0	20.3	10.6	5.5	1.9	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	17.8	24.3	19.6	11.2	5.3	1.3	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						0.0	9.4	17.1	16.1	10.4	5.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						0.0	5.5	14.0	14.2	10.4	5.7	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0					
Feb						0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.1	36.6	0.0					
Mar							0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	92.5	0.0						
Apr							0.0	36.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.3							
May							0.0	0.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	40.2							
Jun								0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	21.0							
Jul								0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	42.9							
Aug							0.0	8.8	97.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	89.7							
Sep							0.0	75.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	72.3							
Oct						0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	46.5	0.0						
Nov						0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6	0.0						
Dec						0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	1.8	4.8	6.6	6.5	4.9	3.0	0.7	0.0	0.0					
Feb						0.0	0.0	0.0	0.0	1.2	4.2	8.4	10.7	10.6	8.0	5.0	1.2	0.0	0.0					
Mar							0.0	0.0	0.9	4.3	7.7	13.7	17.0	16.3	12.3	6.4	0.2	0.0						
Apr							0.0	0.0	2.0	7.1	12.5	21.0	26.8	24.0	14.7	5.2	0.0							
May							0.0	0.0	1.3	7.7	16.8	24.5	28.1	21.0	9.3	0.5	0.0							
Jun								0.0	0.2	6.7	13.4	20.7	24.6	18.9	6.3	0.0	0.0							
Jul								0.0	0.2	6.2	14.0	20.9	26.4	21.4	8.6	0.0	0.0							
Aug							0.0	0.0	1.5	6.8	13.9	22.3	30.8	24.8	13.2	5.2	0.0							
Sep							0.0	0.0	2.1	6.6	10.5	18.0	21.1	17.8	13.8	4.7	0.0							
Oct						0.0	0.0	0.0	0.8	3.6	7.6	11.7	13.5	10.6	8.5	3.4	0.0	0.0						
Nov						0.0	0.0	0.0	0.0	0.8	3.9	6.7	8.0	6.6	5.2	2.3	0.2	0.0						
Dec						0.0	0.0	0.0	0.0	0.0	1.7	4.3	5.9	5.2	4.0	2.0	0.3	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	43.0	0.0					
Feb						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	29.2	0.0					
Mar							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	92.4	1.2						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	65.9							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	29.9							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	18.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	36.6							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	68.2							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	57.1							
Oct						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	60.1	0.0						
Nov						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.0						
Dec						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	33.4	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	5.2	9.7	16.0	26.4	0.0	0.0					
Feb						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	4.6	9.1	15.4	26.2	0.0	0.0					
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.4	4.3	8.9	15.1	21.0	0.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	0.3	4.1	8.3	12.7	4.7							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	6.3	5.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	2.6	4.3	2.1	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	2.6	5.0	3.8	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	7.2	9.4	1.3							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	1.1	5.1	9.7	16.0	2.8							
Oct						0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	6.5	11.6	19.4	19.1	0.0						
Nov						0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	6.9	12.0	19.8	31.7	0.0						
Dec						0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	6.1	10.7	17.3	28.7	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	98.3	80.4	27.6					
Feb						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	96.7	90.1	56.6	0.9					
Mar							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	99.6	82.2	75.7	30.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	84.5	56.7	33.4							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	57.0	30.2	13.1							
Jun								0.0	-0.0	0.0	0.0	0.0	0.0	100.0	54.1	12.3	4.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	100.0	62.4	19.1	11.2							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	78.9	45.7	26.7							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	92.8	70.7	48.5							
Oct						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	87.3	82.6	28.4						
Nov						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	98.1	97.1	48.7						
Dec						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	99.5	68.3	27.4					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	99.9	92.1	93.8	0.0					
Feb						0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	95.6	55.3	21.2	0.0					
Mar							0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	81.7	20.6	0.0						
Apr							0.0	77.4	100.0	100.0	100.0	100.0	100.0	100.0	97.3	76.3	18.2							
May							0.0	45.1	100.0	100.0	100.0	100.0	100.0	100.0	98.8	79.4	17.1							
Jun								30.8	100.0	100.0	100.0	100.0	100.0	100.0	99.6	84.5	9.5							
Jul								46.2	100.0	100.0	100.0	100.0	100.0	100.0	99.8	85.0	23.2							
Aug							0.0	42.4	100.0	100.0	100.0	100.0	100.0	100.0	98.6	81.1	29.3							
Sep							0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	96.4	69.4	7.4							
Oct						0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	73.5	15.7	0.0						
Nov						0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	95.5	72.4	0.0						
Dec						0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	94.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.2	0.5	2.0	5.5	9.4	15.2	25.1	21.9	0.0					
Feb						0.0	0.0	0.0	0.0	0.2	0.6	0.8	1.7	5.5	9.4	15.7	27.0	12.2	0.0					
Mar							0.0	0.0	0.4	0.9	1.2	1.4	2.1	6.1	9.9	15.2	18.6	0.0						
Apr							0.0	0.1	1.6	1.8	2.1	2.3	2.9	6.7	9.8	4.0	0.0							
May							0.0	0.0	2.4	2.9	3.0	3.2	3.6	6.9	5.0	0.0	0.0							
Jun								0.0	2.3	3.6	3.6	3.8	4.2	6.9	2.9	0.0	0.0							
Jul								0.0	2.1	3.3	3.3	3.5	3.9	6.8	5.2	0.0	0.0							
Aug							0.0	0.0	2.0	2.3	2.4	2.7	2.9	6.6	8.7	0.1	0.0							
Sep							0.0	0.2	0.9	1.3	1.5	1.8	3.2	6.9	11.2	12.3	8.6							
Oct						0.0	0.0	0.0	0.2	0.6	0.9	1.1	3.7	7.4	12.3	20.4	23.0	0.0						
Nov						0.0	0.0	0.0	0.0	0.1	0.4	0.6	3.5	7.0	11.6	19.0	30.2	0.0						
Dec						0.0	0.0	0.0	0.0	0.0	0.2	0.4	2.8	6.2	10.3	16.5	27.3	18.7	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						99.8	99.3	98.3	96.0	79.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						99.9	99.3	98.0	91.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							99.2	94.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							24.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Sep							98.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Oct						99.7	98.7	94.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						99.6	98.9	97.4	91.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						99.7	99.1	98.1	95.7	80.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.2	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	4.7	3.8	1.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	1.7	2.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Oct						0.0	1.9	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						1.5	4.3	2.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						2.1	5.5	3.7	1.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						16.7	44.0	51.1	54.4	53.2	47.0	23.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Feb						0.0	37.7	52.1	55.7	55.0	49.6	34.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Mar							31.3	55.1	56.4	54.8	49.7	36.8	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							17.8	47.2	52.8	52.1	48.6	38.3	0.0	0.0	0.0	0.0	0.0							
May							0.0	29.2	49.4	49.5	48.0	40.2	0.0	0.0	0.0	0.0	0.0							
Jun								18.5	47.9	48.4	48.1	42.2	1.1	0.0	0.0	0.0	0.0							
Jul								19.8	48.4	48.8	48.4	42.7	4.4	0.0	0.0	0.0	0.0							
Aug							0.0	35.7	51.3	51.0	48.9	40.8	0.0	0.0	0.0	0.0	-0.0							
Sep							33.3	56.6	55.0	53.2	47.9	32.8	0.0	0.0	0.0	0.0	-0.0							
Oct						19.6	48.9	55.0	56.6	53.1	45.2	9.3	0.0	0.0	0.0	0.0	0.0	-0.0						
Nov						28.5	47.8	53.1	54.9	52.0	42.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						25.6	45.9	51.7	53.7	51.8	43.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						71.1	82.8	89.3	69.9	11.0	0.0	0.0	0.0	0.0	-0.0	-0.0	0.0	0.0	0.0					
Feb						75.7	90.3	89.7	44.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.0	0.0	0.0					
Mar							100.0	65.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							93.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
May							0.0	0.0	0.0	-0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Jul								0.0	0.0	-0.0	0.0	0.0	0.0	-0.0	0.0	0.0	0.0							
Aug							0.0	0.0	0.0	0.0	-0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Sep							95.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Oct						85.8	96.3	64.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Nov						76.3	90.0	84.4	42.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Dec						71.7	81.5	88.9	67.5	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.9	71.5	80.1	62.8	33.6	21.6	16.6					
Feb						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.0	75.3	58.1	31.7	23.2	19.0					
Mar							-0.0	0.0	0.0	0.0	0.0	0.0	0.0	64.4	65.9	47.6	28.0	23.6						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	0.0	59.0	54.1	39.6	30.6							
May							0.0	0.0	0.0	0.0	0.0	0.0	0.0	54.1	46.3	38.4	35.4							
Jun								0.0	0.0	0.0	0.0	0.0	0.0	53.2	45.3	30.1	38.7							
Jul								0.0	0.0	0.0	0.0	0.0	0.0	52.4	47.6	30.1	37.7							
Aug							0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.8	51.6	39.2	33.2							
Sep							0.0	0.0	0.0	0.0	0.0	0.0	6.6	61.3	58.1	40.0	27.2							
Oct						0.0	0.0	-0.0	0.0	0.0	0.0	0.0	47.5	71.8	66.6	41.2	21.9	21.7						
Nov						-0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.3	75.8	76.0	47.9	26.6	20.1						
Dec						0.0	-0.0	0.0	0.0	0.0	0.0	0.0	45.8	75.5	81.3	57.4	30.3	20.1	15.0					

Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan						2.4	6.0	3.8	2.4	1.3	0.7	0.1	0.0	1.2	2.3	2.7	2.7	4.7	0.0					
Feb						0.0	7.1	4.4	2.4	1.6	0.9	0.3	0.0	1.0	2.1	2.5	2.7	4.8	0.0					
Mar							2.2	5.0	2.9	1.8	1.1	0.5	0.0	0.9	1.8	2.4	3.6	0.3						
Apr							0.0	6.4	3.5	2.0	1.1	0.5	0.0	0.7	1.8	2.5	4.3							
May							0.0	2.9	3.0	1.8	1.1	0.5	0.0	0.7	1.5	3.4	0.0							
Jun								0.0	3.6	2.1	1.3	0.6	0.0	0.6	1.5	3.7	0.0							
Jul								0.0	3.6	2.1	1.3	0.7	0.0	0.5	1.3	3.2	0.0							
Aug							0.0	6.3	3.5	2.0	1.1	0.5	0.0	0.6	1.6	2.6	3.5							
Sep							2.4	4.7	2.8	1.8	1.0	0.3	0.0	1.0	2.0	2.4	5.2							
Oct						0.5	6.4	3.5	2.1	1.3	0.7	0.0	0.3	1.5	2.3	2.4	4.2	0.0						
Nov						3.9	5.4	3.2	1.8	1.1	0.6	0.0	0.5	1.6	2.7	2.4	3.4	3.4						
Dec						4.4	5.5	3.4	2.1	1.1	0.6	0.0	0.3	1.4	2.6	2.6	3.0	4.5	0.0					

Appendix C-1: Ground floor spaces GVCP and DGI

					Angles of view (-ve angles to right and +ve angles to left)												
Space	Season	Glare metrics	Average luminance (cd/m2)	Glare threshold (cd/m2)	60	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
35	Summer	GVCP	16.12	112.84	72.02	59.98	48.87	39.65	32.68	28.95	27.56	29.55	34.25	41.81	51.56	63.02	75.03
		DGI			15.03	16.76	18.23	19.45	20.43	20.97	21.18	20.88	20.2	19.16	17.87	16.33	14.53
	Winter	GVCP	8.39	58.73	83	73.29	63.25	54.09	46.6	42.35	40.68	42.9	48.07	55.95	65.36	75.42	84.87
		DGI			13.64	15.38	16.86	18.1	19.09	19.64	19.86	19.57	18.9	17.86	16.58	15.04	13.23
37	Summer	GVCP	47.21	330.47	39.61	45.45	50.99	54.99	55.13	53.89	52.36	48.96	40.52	35.13	38.53	38.4	44.53
		DGI			0	22.44	0	20.31	19.69	19.64	19.92	20.66	21.68	22.02	21.57	21.25	20.47
	Winter	GVCP	7.34	51.38	75.82	71.07	64.79	59.29	52.21	46.55	42.34	40.65	40.87	42.22	47.24	50.96	59.68
		DGI			0	19.27	0	21.55	22.56	23.4	24.07	24.37	24.4	24.03	23.41	22.85	21.7
39	Summer	GVCP	81.01	567.07	68.53	61.53	55.27	49.1	45.89	45.89	48.87	50.73	53.99	60.39	66.93	75.22	82.64
		DGI			17.51	18.36	19.11	19.93	20.34	20.26	19.75	19.57	19.28	18.54	17.37	16.19	15.05
	Winter	GVCP	24.34	170.38	69.84	78.74	77.49	74.63	71.33	68.22	64.82	60.98	58.43	55.6	47.76	50.77	54.02
		DGI			17.43	0	17.63	17.46	17.55	17.81	18.38	19.24	20.03	20.82	21.97	21.73	20.93
41	Summer	GVCP	62.13	434.91	86.57	78.66	69.16	57.63	47.02	38.23	32.23	27.2	24.02	23.62	24.84	28.55	34.87
		DGI			0	14.97	16.79	18.43	19.92	21.22	22.16	23.1	23.79	23.98	23.86	23.31	22.37
	Winter	GVCP	9.91	69.37	92.63	89.06	84.86	79.59	74.06	71.2	68.15	68.43	69.15	71.54	75.27	80.15	85.61
		DGI			0	14.71	15.85	16.83	17.8	18.15	18.65	18.66	18.69	18.5	18.1	17.45	16.56
42	Summer	GVCP	70.26	491.82	28.66	24.22	22.88	23.54	25.94	29.93	36.86	45.44	55.8	67.14	76.68	85.74	91.75
		DGI			23.62	24.27	24.3	24	23.38	22.63	21.4	20.07	18.57	16.92	15	12.83	10.05
	Winter	GVCP	20	140	52.93	46.05	42.76	41.97	44	48.41	55.22	63.71	72.94	81.92	88.28	94.25	97.06
		DGI			21.86	22.78	23.16	23.17	22.79	22.08	21.06	19.79	18.33	16.68	14.82	12.81	9.6
43	Summer	GVCP	44.97	314.79	61.53	50.82	42.27	34.74	28.76	26.22	27.12	27.56	31.77	39.16	47.4	57.33	68.61
		DGI			18.01	19.36	20.4	21.42	22.36	22.69	22.4	22.35	21.64	20.49	19.35	18.02	16.44
	Winter	GVCP	77.46	542.22	77.87	69.08	57.16	46.1	36.93	30.4	25.07	22.75	19.83	20.55	24.65	30.71	37.36
		DGI			15.11	16.75	18.25	19.63	20.86	21.81	22.76	23.24	24.07	23.99	23.25	22.31	21.43
45	Summer	GVCP	38.83	271.81	56.91	43.4	32.51	24.61	19.44	14.8	12.06	15.16	19.82	25.22	33.36	44.51	58.2
		DGI			15.36	17.11	18.59	19.8	20.71	21.7	22.53	21.61	20.65	19.71	18.49	16.99	15.21
	Winter	GVCP	63.71	445.97	80.31	70.65	60.73	51.58	44.09	37.41	33.16	31.3	28.72	33.52	39.92	46.54	54.65
		DGI			14.97	16.63	18.16	19.55	20.76	21.89	22.74	23.24	24.29	23.49	22.58	21.81	20.78
46	Summer	GVCP	98.93	692.51	70.08	58.97	49.7	40	32.87	27.92	25.31	24.48	26.75	30.18	38.85	46.71	55.53
		DGI			16.75	18.22	19.32	20.74	21.76	22.5	23.03	23.3	23.01	22.47	21.16	20.17	19.14
	Winter	GVCP	3.95	27.65	95.07	91	85.87	80.13	74.4	69.84	67.82	67.88	70.35	74.58	79.75	85.39	90.62
		DGI			13.93	15.7	17.23	18.56	19.68	20.51	20.93	20.97	20.62	19.94	19.03	17.84	16.41
48	Summer	GVCP	77.5	542.5	49.37	48.43	50.12	53.57	56.12	60.45	65.95	73.69	81.6	88.07	91.56	93.51	96.25
		DGI			21.18	20.92	20.31	19.44	18.86	18.05	17.13	15.79	14.28	12.83	11.25	9.26	7.38
	Winter	GVCP	3.17	22.19	76.68	75.14	73.63	74.69	77.41	81.09	85.57	89.97	93.72	96.39	98.02	99.29	99.75
		DGI			0	20.02	20.1	19.68	18.92	17.96	16.74	15.32	13.75	12.21	10.61	7.86	5.84
49	Summer	GVCP	216.96	1518.72	46.8	42.66	40	38.34	38.39	38.73	41.2	47.57	54.86	61.41	66.09	76.48	80.84
		DGI			20.8	21.04	21.22	21.37	21.35	21.43	21.2	20.29	19.36	18.49	17.23	15.73	13.88
	Winter	GVCP	2.96	20.72	85.26	84.64	84.71	85.52	87.43	89.92	92.6	95.29	97.28	98.62	99.32	99.73	99.92
		DGI			19.09	18.82	18.41	17.89	17.09	16.12	14.98	13.58	12.1	10.16	8.46	6.58	4.13

Appendix C-2: Top floor spaces GVCP and DGI

					Angles of view (-ve angles to right and +ve angles to left)												
Space	Season	Glare metrics	Average luminance (cd/m2)	Glare threshold (cd/m2)	60	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
3	Summer	GVCP	7.49	52.42	75.24	66.67	58.84	52.91	49.44	48.93	51.15	55.96	62.99	71.31	79.83	87.54	92.19
		DGI			17.52	18.88	19.99	20.8	21.24	21.28	20.95	20.27	19.24	17.96	16.46	14.73	12.72
	Winter	GVCP	4.60	32.22	84.3	77.69	71.05	66.31	63.31	62.81	65.64	70.2	76.34	83.02	89.14	94.02	96.66
		DGI			16.13	17.43	18.52	19.22	19.62	19.67	19.21	18.49	17.43	16.12	14.59	12.83	10.82
5	Summer	GVCP	9.62	67.37	40.24	34.29	36.22	39.74	44.86	52.73	62.3	72.59	82.36	90.32	95.68	98.52	99.51
		DGI			23.46	24.3	23.82	23.12	22.23	20.95	19.44	17.71	15.77	13.62	11.28	6.58	4.24
	Winter	GVCP	5.75	40.28	51.1	45.57	48.17	52.57	58.59	66.65	75.46	83.89	90.89	95.73	98.43	99.84	99.96
		DGI			21.88	22.62	22.08	21.3	20.29	18.94	17.36	15.55	13.52	11.29	8.84	3.06	0.72
7	Summer	GVCP	16.89	118.25	37.34	42.38	44.5	49.11	64.61	68.02	69.99	69.95	67.88	56.2	48.55	40.14	33.45
		DGI			22.75	22.38	21.91	21.1	20.18	19.29	18.85	19.09	19.97	21.11	22.37	23.33	24.06
	Winter	GVCP	38.35	268.46	21.46	18.24	18.87	17.47	25.25	27.3	30.63	34.16	37.35	36.28	35.84	35.22	28.35
		DGI			25.53	0	26.48	26.74	26.29	25.73	25.02	24.46	24.24	24.36	24.84	24.99	25.15
11	Summer	GVCP	46.29	324.00	68.91	59.51	50.84	42.99	37.85	36.19	35.84	37.42	40.36	47.94	56.63	65.5	75.19
		DGI			17.47	18.62	19.64	20.61	21.25	21.38	21.44	21.23	20.94	19.94	18.82	17.73	16.38
	Winter	GVCP	61.27	428.91	84.17	78.22	69.26	60.64	51.37	43.99	39.86	38.14	36.44	33.95	41.17	47.19	54.72
		DGI			0	15.23	16.73	18.06	19.44	20.74	21.53	21.98	22.63	23.57	22.28	21.66	20.79
14	Summer	GVCP	81.64	571.48	97.24	93.76	88.99	80.63	73.5	63.89	54.9	46.13	38.96	34	33.43	34.56	36.4
		DGI			0	0	12.81	0	16.66	18.18	19.55	20.92	22.1	23.06	23.33	23.33	23.33
	Winter	GVCP	60.46	423.19	96.1	93.38	92.23	89.81	87.3	86.13	83.94	82.45	81.63	81.57	82.21	83.72	85.1
		DGI			10.43	0	12.14	12.73	0	13.99	14.56	15.02	15.39	15.67	15.81	15.73	15.75
15	Summer	GVCP	23.85	166.92	82.92	73.97	64.79	56.59	49.22	43.38	42.09	44.56	51.2	58.07	66.66	75.88	84.63
		DGI			15.72	17.34	18.73	19.88	20.9	21.76	21.99	21.67	20.7	19.79	18.6	17.19	15.57
	Winter	GVCP	36.47	255.29	52.27	38.7	28.17	20.71	15.8	13.12	13.09	15.58	20.39	27.69	38	51.3	66.51
		DGI			13.14	14.78	16.17	17.32	18.21	18.79	18.81	18.27	17.4	16.28	14.92	13.34	11.49
16	Summer	GVCP	51.22	358.53	44.04	46.09	51.4	58.41	67.05	76.77	85.97	93.1	97.42	99.83	100	100	100
		DGI			23.71	23.15	22.11	20.85	19.29	17.37	15.13	12.56	9.66	2.42	0	0	0
	Winter	GVCP	950.67	6654.69	100	100	100	100	100	100	100	100	100	100	100	100	100
		DGI			0	0	0	0	0	0	0	0	0	0	0	0	0
18	Summer	GVCP	45.45	318.12	50.25	48.32	47.51	49.36	52.98	57.76	63.26	70.55	77.57	84.38	88.76	93.03	95.74
		DGI			23.15	22.91	22.67	22.01	21.12	20.13	19.24	18.14	17.07	15.86	14.62	13.29	11.79
	Winter	GVCP	7.70	53.93	45.58	47.02	50.05	54.34	59.04	63.59	63.87	65.72	69.96	73.54	77.05	82.11	84.11
		DGI			22.82	22.39	21.71	20.9	20.13	19.57	19.28	19.33	19.21	18.98	18.42	17.53	16.48
22	Summer	GVCP	151.15	1058.05	80.46	75.12	72.6	71.17	67.51	65.17	63	63.22	63.72	65.72	69.07	72.43	73.97
		DGI			15.73	0	0	17.16	17.5	17.63	0	17.74	17.59	17.3	16.91	16.55	15.99
	Winter	GVCP	63.30	443.07	100	99.33	94.52	87.42	75.66	70.41	56.68	56.13	44.95	35.97	29.02	24.54	21.66
		DGI			0	2.44	8.62	12.62	15.21	18.21	0	22.46	24.22	25.7	27	27.97	28.74
23	Summer	GVCP	40.31	282.15	26.38	37.36	54.91	63.1	65.6	65.66	62.46	58.47	54.97	46.04	42.25	38.51	39.18
		DGI			23.43	0	21.66	20.56	19.72	19.45	19.78	20.53	21.32	21.97	22.83	23.31	23.54
	Winter	GVCP	11.05	77.37	52.17	54.58	53.98	48.27	45.43	42.54	39.37	37	36.84	33.67	33.5	37.19	42.2
		DGI			21.34	21.38	21.59	22.07	22.78	23.53	23.98	24.42	24.49	24.46	24.4	24.12	23.6

Appendix D-1: Ethics clearance

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

SCHOOL OF ARCHITECTURE PLANNING

23 February 2022

Faculty of Engineering and the Built Environment:

Ethics clearance letter:

Dear Ochuko Overen

Student number (2485738), this letter confirms that your ethics application has been cleared. Your clearance/protocol number SOAP139/06/2021

Yours sincerely

Lerato Nkosi

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