http://periodicos.sbu.unicamp.br/ojs/index.php/parc
https://doi.org/10.20396/parc.v15i00.8673145

DAYLIGHTING IN MODERNIST EDUCATIONAL ARCHITECTURE IN THE UNITED KINGDOM: THE MARYLEBONE BUILDING IN LONDON

LUZ NATURAL NA ARQUITETURA MODERNISTA EDUCACIONAL NO REINO UNIDO: O EDIFICIO MARYLEBONE EM LONDRES

Sylvia Tavares Segovia[1]

Rosa Schiano-Phan [2]

Joana Carla Soares Gonçalves[3]

Roberta Consentino Kronka Mulfarth[4]

1 Klaus Bode Consultancy, London, UK sylvia.segovia@alumni.usp.br
2 University of Westminster, London, UK, r.schianophan@westminster.ac.uk
3 University College London & Architectural Association School of Architecture, London, UK, joana.goncalves@ucl.ac.uk
4 Universidade de São Paulo, São Paulo, SP, Brasil, r.kronka@usp.br

Authors' contributions:
STS: conceptualization, data curation, formal analysis, investigation, methodology, project administration, programs, supervision, visualization, writing - original draft, writing - review and editing. **RSP**: conceptualization, data curation, formal analysis, investigation, methodology, project administration, supervision, visualization, writing-original draft, writing-review & editing. **JCSG**: conceptualization, data curation, formal analysis, investigation, methodology, supervision, visualization, writing-original draft, writing-review & editing. **RCKM**: conceptualization, methodology, project administration, supervision, writing-review & editing.

Funding: Fundação de Amparo à Pesquisa do Estado de São Paulo.

Declaration of conflict: none declared.

Responsible Editor::
Maria Fernanda de Oliveira

Abstract

The consideration of environmental quality in buildings became prominent in the Modernist movement in the UK and on the international scene, after the Second World War, including the emphasis on daylight access, particularly in educational buildings. The Marylebone building of the University of Westminster (1970s), in central London, is an example of this architectural trend. With rooflights, tilted ceilings, double height spaces and other features, this is a late modernist example of optimised daylighting design in educational buildings in the United Kingdom. However, the north-south symmetrical approach to the rooflights and the distribution of internal spaces raise questions about the efficiency of daylight. Hence, the aim of this technical study was to assess the daylight performance of the Marylebone building, considering its original and current layouts, with the use of Climate-Based Daylight Modelling (CBDM). Performance criteria included Useful Daylight Illuminance (UDI), Daylight Factor (DF), Illuminance levels and Glare Probability. Among the main results, it was found the achievement of the minimum threshold of 300 lux for most of the year (equivalent to 2% DF). Risks of glare were identified closer to windows and under the rooflights on the south side. It is concluded that the daylight strategies of the project were attuned to the activities and furniture layout of the atelier studio of the 1970s but not fully suitable for the use of personal computers that replaced the drawing boards in the 1990s, due to the excessive illuminance levels and penetration of direct solar radiation, leading to the recent insertion of internal blinds.

Keywords: *Daylight, modernist architecture, study-spaces, performance assessment, computer simulation.*

Resumo

A consideração da qualidade ambiental nos edifícios tornou-se proeminente no movimento modernista, no Reino Unido e no cenário internacional, após a Segunda Guerra Mundial, incluindo a ênfase ao acesso à luz natural, particularmente em edifícios educacionais. O edifício Marylebone da Universidade de Westminster (da década de 1970), no centro de Londres, é um exemplo dessa tendência arquitetônica. Com claraboias, tetos inclinados, espaços de pé-direito duplo e outros recursos, este é um exemplo modernista tardio de projeto otimizado de iluminação natural em edifícios educacionais no Reino Unido. No entanto, a abordagem simétrica norte-sul das claraboias e da distribuição dos espaços internos levantam questões sobre a eficiência da luz natural. Assim, o objetivo deste estudo técnico foi avaliar o desempenho da luz natural no edifício Marylebone, considerando seus layouts originais e atuais, com o uso de Climate-Based Daylight Modeling (CBDM). Os critérios de desempenho incluíram Iluminância Útil da Luz do Dia (UDI), Fator da Luz do Dia (FLD), níveis de Iluminância e Probabilidade de Brilho (ofuscamento). Dentre os principais resultados, constatou-se o alcance do mínimo de 300 lux pela maior parte do ano (equivalente a 2% de FLD). Riscos de ofuscamento foram identificados próximo às janelas e sob as claraboias do lado sul. Concluiu-se que as estratégias de aproveitamento da luz natural do projeto eram adequadas às atividades do ateliê de 1970, mas não integralmente apropriadas ao uso de computadores que substituíram as pranchetas na década de 1990, por conta do excesso de luminosidade e penetração da radiação solar direta, levando à inserção recente de persianas internas.

Palavras-chave: Luz natural, arquitetura modernista, espaços de estudo, avaliação de desempenho, simulação computacional.

How to cite this article:

SEGOVIA, Sylvia; SCHIANO-PHAN, Rosa; GONÇALVES, Joana Carla; MULFARTH, Roberta. Daylighting in modernist educational architecture in the United Kingdom : the Marylebone building London. **PARC: Pesquisa em Arquitetura e Construção**, Campinas, SP, v. 15, n. 00, p. e024020, 2024. DOI:https://doi.org/10.20396/parc.v15i00.8673145

Submitted 17.04.2023 – Approved 25.09.2024 – Published 9.12.2024

Introduction

Designing with daylight and the modernist legacy

A creative use of daylight and sunlight has been seen in the work of key names from the international modern architecture. This is the case of Le Corbusier's sacred buildings (Lau, 2008), Alvar Aalto's daylit libraries and civic buildings (Sanchez Jaime; Lau, 2012) and Carlo Scarpa's well-crafted museums (Zhou; Lau, 2017), to name a few examples that successfully integrated daylighting design in architectural tectonics. Building on this trend, the iconic examples of modernist architecture throughout most of the 20th century in the UK made use of a set of strategies to enhance the architectural quality and environmental comfort of buildings (Bone, 2014). With respect to daylight, rooflights, high-level windows, double height spaces were commonly found among modernist educational buildings in the UK (RIBA, 2019).

Following the principles of daylight, such design features contribute to a more homogeneous distribution of daylight in space, whilst allowing for daylight to reach inner areas, further from the facade (Baker; Steemers, 2002). The roof skylight, in particular, is a prevalent architectural solution in temperate and cold climates to maximize and enhance daylight in buildings (Baker; Steemers, 2002; Phillips, 2004; Tregenza; Wilson, 2013), where sky conditions show low levels of daylight availability in winter and mid-season days, coupled with a high frequency of overcast hours. Regarding the illuminance distribution in overcast skies, it is generalized that the area around the zenith has 3 times more intensity than the horizon, justifying the advantage of skylights and high-level openings that minimize the impact of external obstructions of sky views (Moore, 1991). Looking beyond the daylight benefits, skylights have also been used in these climates for passive solar gains, during the cooler periods of the year. As opposed to that, in warm climates, skylights are associated with greater risks of overheating (Al-Obaidi; Mazranismail; Rahman, 2014) and require appropriate solar protection in heritage buildings (Marzouk; Elsharkawy; Mahmoud, 2022).

During the modernist period, the Greater London Council was responsible for the planning, designing and building of extensive areas of the city of London (Abbott, 2020). In the 1960s, numerous buildings were built, including schools, residential and famous landmark buildings, mainly based on modernist ideals. The Marylebone building of the University of Westminster is one of these buildings.

Today, in light of the global warming and energy crisis worldwide, not much is known about the daylighting performance and strategies adopted in these buildings. Some examples of case study daylighting analysis of buildings of historical significance can be found in the literature (Lecaro *et al*., 2017; Al-Sallal; Abouelhamd; Dalmouk, 2018; Schiano-Phan *et al.,* 2018; Gonçalves *et al.,* 2022) but these are not many. Much can be learnt from critically studying buildings of historical importance and understanding their daylighting performance and the contemporary application potential of their strategies.

Gonçalves *et al.* (2022), for instance, investigated the environmental impacts of horizontal skylights in the building of the Faculdade de Arquitetura e Urbanismo da Universidade de University of São Paulo (FAUUSP) in the city of São Paulo (latitude 23,85°S), of Humid Subtropical Climate (Cfa) (Peel; Finlayson, 2015). The building was opened in 1969 and listed in 1982, a well-known icon of the São Paulo School of Architecture, in which the roof is the expression of a synthesis among structure, space and environment (Russo, 2004). The 18% translucent roof area in this building raises questions about the impact of incident solar radiation during the warmest period of the year upon internal spaces' thermal and daylight conditions. The analytical thermal and daylighting studies of the studio spaces and classrooms examined the improvements brought by the roof refurbishment of 2014, in which the originally transparent domos were replaced by translucent acrylic ones. Among the results, it was noted that the glare associated with the original design was eliminated with the new acrylic skylight of 20% light transmittance, creating a homogeneous lighting environment throughout the year across the building. On the other hand, the uncomfortable thermal conditions were ameliorated but were not eliminated since peak temperatures were calculated at around 30 °C during the year's warmest days.

In this context, this paper aims to fill the research gap of similar studies for the temperate climate, with a focus on the performance of top light, by analytically investigating the impact of the symmetrical skylight solution adopted in the Marylebone Building of the University of Westminster, in London, upon its daylighting conditions, with special attention to the risk of glare.

Daylight: performance metrics

Visual comfort in buildings is usually established when it is possible to see well and perform a task, and there is adequate light to perceive details with no excessive contrast or glare (BREEAM, 2018). This was intuitively understood by architects of the past and recent studies on the application of Daylight Factor calculations to the design of modernist buildings reveal a mixed approach where those architects engaging in the calculations developed a better understanding of the principles of daylighting (Lewis, 2017). Nevertheless, the advantages of daylighting to occupants in buildings go beyond visual comfort. As daylight varies throughout the day, it gives a psychological sense of time and is perceived in a different way than artificial light by the human eye, varying in nuances of colour and spectrum (Wang *et al.,* 2017).

Given the dynamism and complexity of the interaction between humans and the environment, the non-visual aspects from the fields of photobiological sciences and health are recently being added to the daylighting evaluation of buildings (Andersen; Gochenour; Lockley, 2013), which are assessed based on visual comfort aspects (Andersen, 2015). The comfort aspects, which were usually related to the occupant's performance when executing tasks, are added to the notion of well-being with the environment; whereas the health aspects appear to be linked to people's circadian cycles, considering the role of natural light in the control of the numerous biological processes essential to human health (Mardaljevic *et al.,* 2012; Andersen, 2015; Konis, 2017).

In a broader concept of daylight performance, the methods of assessment of daylight performance in buildings have also advanced significantly over the last two decades, as seen in the work of Jakubiec and Reinhart (2011), Lima, Brugnera and Caram (2015) and Nabil and Mardaljevic (2006), to cite a few. Focusing on analytical procedures, points of innovation and increased complexity and precision are associated with the digital modelling process as well as the performance assessment protocols, involving different simulation tools.

The assessment method called Climate-Based Daylight Modelling (CBDM), first introduced by Reinhart and Herkel (2000) and discussed by Nabil and Mardaljevic (2005, 2006) is an alternative to the methods and static criteria of evaluation from earlier decades. The static analyses, also called point-in-time analyses, primarily target the Daylight Factor (DF) performance indicator (Moon; Spencer, 1942). Computer simulation of illuminance levels is also based on the point-in-time calculation. Similar to the thermodynamics evaluations, the dynamic daylight assessment of buildings generates a time series of predictions per point in the grid, usually annual and hourly.

These simulations have realistic sun and sky conditions taken from data from the weather file that allow the output to have extreme values, such as those encountered in real life analyses, in addition to daily and seasonal variations, as explained by Mardaljevic, Andersen and Roy (2012). The two performance-factors which are outcomes of these climate-based daylight simulations are: Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI).

The Daylight Autonomy (DA) metric was first introduced in 1989 by the Association Suisse des Electriciens and later on redefined by Reinhart and Walkenhorst in 2001 (Reinhart; Mardaljevic; Rogers, 2006). DA represents the frequency in a year that a given Illuminance value is achieved at the work plane for which a minimum Illuminance threshold (for example, 300 or 500 lux) is established. Artificial lighting is assumed as not necessary when this predetermined illuminance value is achieved.

The Useful Daylight Illuminance (UDI) metric was proposed by Nabil and Mardaljevic (2005) and can be defined as an annual occurrence of certain illuminance levels at the work plane considered to be useful. The definition of the useful illuminance range was based on results of on-site evaluations that registered the behaviour and preference of occupants in naturally lit buildings with movable shading devices (Mardaljevic *et al.,* 2012).

Looking at the potentials and limitations of performance criteria, daylight factor (DF) simulation is calculated with the CIE Overcast Sky and it is a ratio between the illuminance inside and the illuminance outside measured at the same time (Moon; Spencer, 1942), which does not take into account the real sky conditions like climate-based simulations and, therefore, tend to show symmetry of performances, because it is insensitive to glazing orientation (due to the overcast sky condition). However, it still considers the obstruction of surrounding buildings. The Daylight Autonomy (DA) simulations are similar to UDI simulations. However, DA shows how often in a year the minimum work plane threshold illuminance is achieved without the need for artificial light, whilst UDI also states an upper limit, expressing how often a certain range is achieved; therefore, it gives a broader understanding of the actual daylight performance. The symmetry of DF simulations does not appear in DA or UDI analysis.

Initially, UDI was determined by the range between 100 and 2000 lux. Currently, the expansion or reduction of the range is being discussed, always based on field studies being done in office buildings or of other building types in different locations. The work of Mardaljevic *et al.* (2012) considers the range between 300 a 3000 lux as satisfactory Illuminance levels, with between 100 and 300 being supplemental in need of artificial lighting, below 100 lux failing, being insufficient, and above 3,000 lux as exceeding comfort levels with a high risk of glare.

The Illuminating Engineering Society (IES) defines glare as "the sensation produced by luminances within the visual field that are sufficiently greater than the luminances to which the eyes are adapted to, causing annoyance, discomfort, or loss in visual performance or visibility" (IES, 2023). High levels of daylight above the UDI threshold of 3000 lux, for example, are usually associated with complex problems such as overheating and glare (Pierson; Wienold; Bodart, 2018). Tagliabue, Buzzetti and Arosio (2012) affirm that discomfort caused by glare may lead occupants to adapt to their internal conditions, which can cause an inferior daylight performance than it is expected and needed (Marcondes Cavaleri; Cunha; Gonçalves, 2018).

The metric used for glare analysis is Daylight Glare Probability (DGP), which considers the overall brightness of the scene in the occupant's field of view, position of glare sources and visual contrast. DGP was introduced by Wienold and Christoffersen in

Towards a New Daylight Glare Rating (Wienold; Christoffersen, 2005) and it is based on the analysis of HDR images through the Radiance based Evalglare tool (Wienold *et al.*, 2004), being able to deal with large glare sources such as the sun. The simulations generate 4 different types of images: renders with a DGP level for the selected scene and highlighted areas, in which luminance is above 2000 cd/m², coupled with false colour images generated from HDR renders of the selected view on the specific time and date; annual glare on a horizontal grid with pie slices for each view direction and a map of annual glare.

The annual glare calculation is done by repeating the point-in-time glare process for each hour of the year to calculate vertical illuminance and contrast from direct sunlight, which generates an annual evaluation of comfort of the selected view.

By adopting the CBDM analysis method, the purpose of this study was to quantify the daylight performance and qualify the visual environment of the educational building of the Marylebone building of the University of Westminster, considering the current occupation, looking at the results of annual Useful Daylight Illuminance (UDI). For the visual comfort conditions, Glare Probability studies were also carried out on the top floors, where the luminous environment is highly influenced by the rooflights.

Case-study: the Marylebone Building

Building design

Designed by the Greater London Council (GLC) Architect's Department - Educational Section and built in 1973 by Taylor Woodrow Ltd., the slab-like building of the then Polytechnic of Central London, also known as the Marylebone building, was conceived in a period of great expansion of the British higher education infrastructure (UCL, 2017). The building is one of the late examples of modernist architecture in London and displays all its attributes in the architectural expression of clear forms and highly functional spatial arrangements as well as in the quality of the indoor environments, with particular emphasis on capturing solar access and daylight through the side and top apertures.

Whilst modifications in the internal layout on various floors have been made since its completion in 1973, the building appears not to have changed much from the outside (Figure 1). However, some small but significant changes have taken place both in the way that the building connects with the public realm and in the finishes of the façade. For example, in the 70s the building was open to the public and physically and visually connected to the street via the stairs from the pavement to the podium level leading to the stairwells and open courtyard; the original finish of the building was bare concrete, resonating with other examples of brutalist architecture of the period; and finally, from the archival photo, it can be seen that the original clear glass windows were changed for green tinted glass, as shown in the 2020 photo (the tinted glass was introduced in the 2012 refurbishment and is an unnecessary choice for a north facing façade). The effect of the change of glass type upon the daylight conditions is tested in this study.

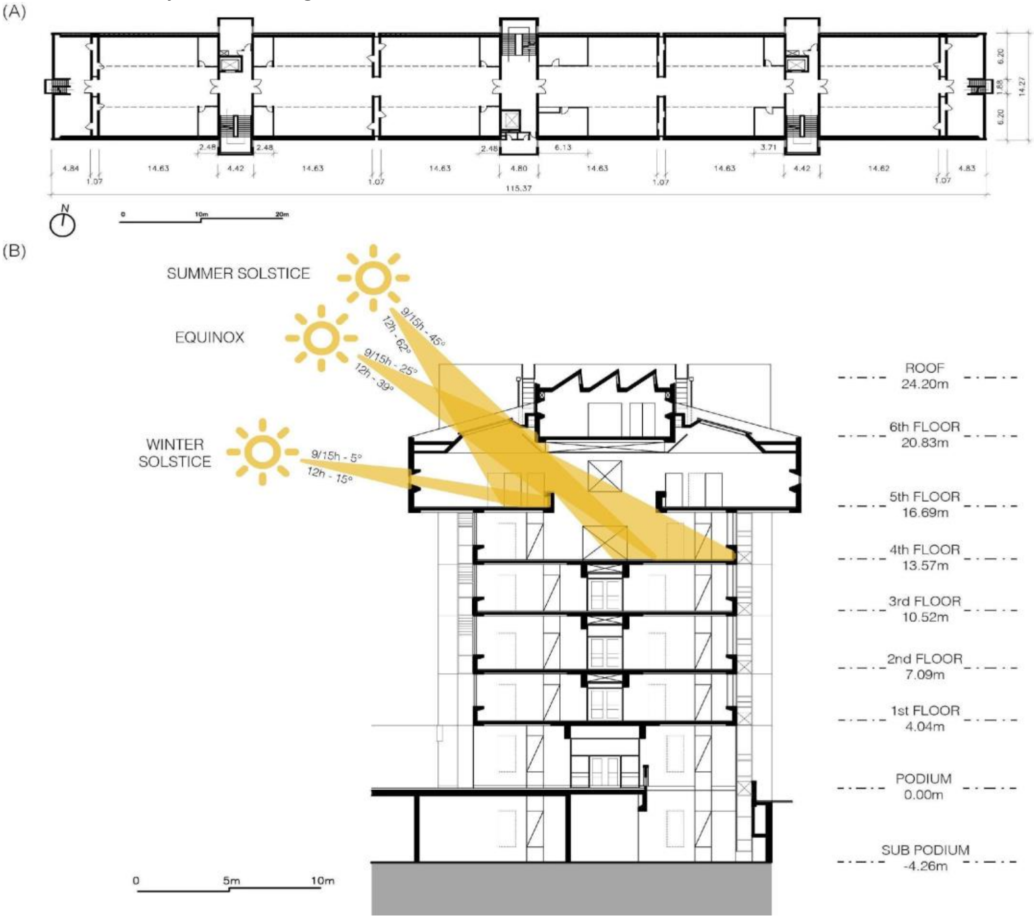
The flexibility of the internal layout is particularly evident in the architectural studios where, at the time of the building being first occupied, architectural education was delivered in an atelier style space, with the provision of tilted and vertical drawing boards, which benefited from the top light coming from the roof-lights and ribbon windows offering a view to the outside to students standing or sitting on stalls next to the drawing boards. This made for a very modern, bright and stimulating environment, fitting for a purpose-built educational building, housing the largest and oldest Polytechnic school in central London.

Figure 1 - (left) front north façade of the Marylebone Building in 2020, (right) same façade in the 1970s

Source: the authors (left), University of Westminster Archives (right).

With a built area of approximately 1,700m² on the first four floors, 2,080m² on the 5th and approximately 1,000m² on the 6th, the Marylebone building is currently home to the School of Architecture and Cities and the Westminster Business School. The classrooms and offices are mostly located on the lower floors and their floor area varies from 10m² to 180m², while the upper floors follow a primarily open-plan configuration, with a few cellular meeting rooms and staff offices (Figure 2).

Figure 2 - Drawings of the Marylebone building: (A) 4th floor plan where the studios of the School of Architecture are located; (B) north-south section of the Marylebone Building with the solar altitudes from 9h to 12h, on the winter and summer solstice and equinox

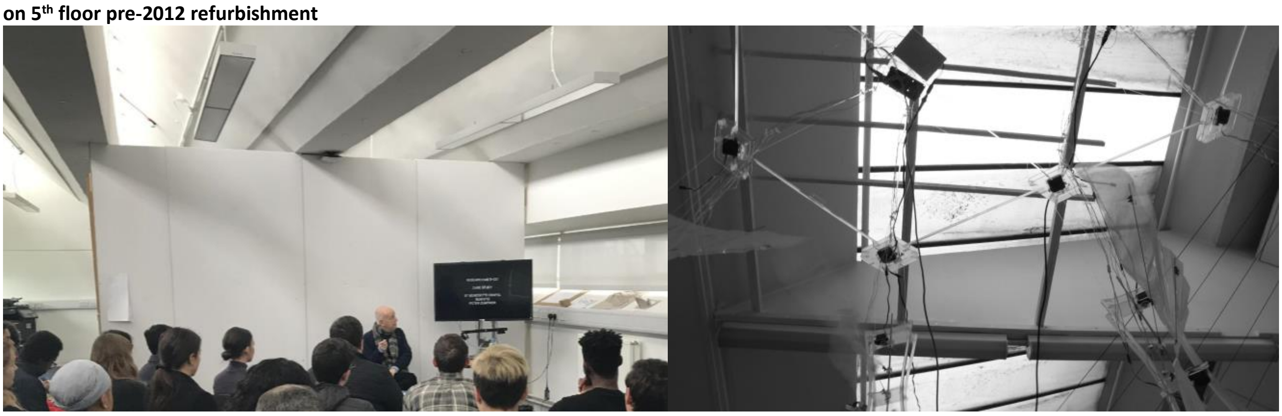


Source: drawings by the authors.

Sitting on a concrete podium 115 meters long and one meter above the street level adjacent to the Marylebone Road, the 6-storey north-south facing building was designed to maximize the benefits of daylight and minimize the risks of overheating. For this purpose, the plan is shallow, with a width of 14.27 meters on the first four floors, expanding to 21 meters on the 5th (mezzanine) floor, where each side is 8 meters deep and the double-height space in the centre of the plan is 5 meters wide. Daylight ingress is through ample glazing areas on the lower floors and through roof-lights, and the tilted ceilings and double-height open-plan spaces on the 4th and 5th floors add visual quality. The surroundings do not impose a significant impact on the building's exposure to solar radiation on the south side, with the only exception of the Marylebone Hall of Residence and the Loughborough Towers on the south.

Roof-lights of different types are located on the 5th and 6th floors (Figure 3). On the 5th floor, they are placed on the sloping roof, facing north and south, originally bringing daylight from the top onto the tilted drawing tables of the 1970s architectural studios. On the 6th floor, the roof follows a *saw tooth* profile, with vertical roof lights facing north maximizing the penetration of diffused and reflected light, which is appropriate for various types of working activities. On both floors, the top light is complemented by side light from the smaller ribbon windows equally distributed on both of the opposite north and south facades, which were designed to maintain a view to the outside for a person standing, while allowing extra daylight access.

Figure 3 - (left) saw-tooth ceiling of 6th floor studio with vertical north facing rooflights; (right) original Georgian style wired-glass fixed roof-lights on 5th floor pre-2012 refurbishment



Source: the authors (left), photographic record of Richard Difford (right).

Currently, the roof-lights on the 5th floor are fitted with internal movable blinds, which moderate the access of direct solar radiation in the open plan studios. The motorised translucent *concertina* blinds were installed in the 2015 refurbishment. However, the original 1970s Georgian style wired-glass fixed roof lights (Figure 3), which had no blinds (except in a few spaces where blackout was required), were replaced in 2012 by a new set of low-e double glazed aluminium framed roof lights, with parallel non-blackout blinds, both manually operated which control the access of direct solar radiation in the open plan studios by a long crank handle. This meant that although the rooflights and blinds operation was not automated or controlled by air quality, temperature or lighting sensors, they were openable and controlled by the occupants' perceived visual and thermal comfort. Nowadays, the rooflights are automated and controlled by CO_2 sensors linked to the Building Management System (Hossain *et al.,* 2020), whereas the blinds are motorised, but controlled by an occupants' operated electric switch on each spatial niche.

The two main facades, north and south, have the same configuration and the same window-to-wall ratio (WWR) of approximately 70% from the 1st to the 4th floors, dropping to around 15% on the 5th and 6th floors. The first four floors have large, double-glazed windows (1.90m high by the whole extension of the room), whilst the 5th and 6th have a smaller window area (0.45m high by the extension of the room), plus the rooflights. The architecture studios are located on the 4th and 5th floors and are visually connected, as the 5th floor is the mezzanine of the 4th, as shown in Figure 4. The plan and section (Figure 2) show how the symmetrical approach to the insertion of the rooflights, coupled with the symmetrical mezzanines, on the north-south oriented building, increases daylight penetration on the south side of the floor (the 5th floor) and on the north side of the 4th floor in comparison to their opposite sides.

Figure 4 – Architecture studios on 4th and 5th floors – Marylebone building

Source: University of Westminster Archives.

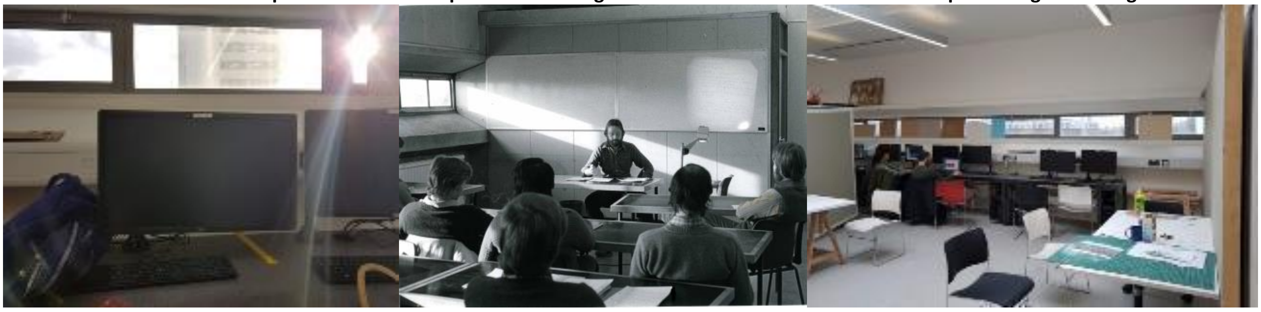
The annual predominance of overcast skies typical of the London climate makes, in principle, the use of rooflights an effective means of improving daylighting performance in buildings. The rooflights positioned on the south side of the rooftop at the 5th floor add to the amount of solar radiation throughout the year, also reaching the 4th floor, during sunny days. In this case, the risk of glare will be a function of the orientation and size of the rooflights, combined with the spatial configuration of the internal spaces and can be quantified by daylighting computational simulation.

The exposure to excessive solar radiation in the warmer periods of the year, due to the south facing rooflights, also poses the threat of overheating. Such a potential risk does not happen on the 6th floor because the rooflights face north, which is predominantly characterized by diffuse radiation. In order to control excessive amounts of daylight and potential glare associated with the rooflights of the 5th floor, automated internal blinds were added in the refurbishment of 2012.

Since its construction, the building has been refurbished a few times. In 2012, GM Rock Townsend Architects closed the previously open courtyard between the university buildings and created the internal ground floor space called 'Learning Platform'. In 2015, the open plan layout was reinstated in the architectural studios on the 4th and 5th floors, which was temporarily lost during a previous cellularization of these spaces in the 1980s (UCL, 2017).

In all the refurbishments, the original open plan concept for the studios on the top two floors was kept, and drawing tables were replaced by a combination of office-like tables, including computers placed on tabletops along the north and south facades. In addition, the change in the way the space is used has compromised some of the early design strategies, causing potential visual discomfort. In this respect, it has been observed that occupants of the 5th floor, working on the computers facing the south facade, have dealt with excessive lighting levels and disability glare by placing cardboards on windows as temporary blinds, as shown in Figure 5. The issue of glare in the Marylebone building is part of the scope of the technical studies presented here.

Figure 5 - (left) noticeable disability glare on a sunny day in winter now, (middle) side light in the 1970s, (right) studio space of the School of Architecture and the use of improvised cardboard panels as shading devices on the south windows as a response to glare during a December day



Source: the authors (left), University of Westminster Archives (middle), the authors (right).

Monitored performance: precedent research work

In order to examine the impact of the building´s orientation on its thermal and daylighting performance, spot measurements of environmental variables were conducted on the 4th and 5th floors of the Marylebone Building, where the architectural studios are located, in the early afternoon of an autumn day with overcast sky conditions in October 2017, by postgraduate students from the master programme in Architectural and Environmental Design of the School of Architecture and Cities of the University of Westminster (Aleem; Munir; Van, 2017). Regarding the daylight conditions, the measurements showed higher illuminance levels on the studios on the south side of the 5th floor, when compared to the north side and to the floor below. In this respect, 1,325 lux was measured on the south side of the 5th floor under the rooflight, while 1,160 lux was measured on the opposite side.

However, at the edge of the south-mezzanine of the 5th floor (slightly further from the projection of the rooflight), 500 lux was recorded, while 700 lux was measured on the north, as an effect of the penetration of solar radiation coming from the south side rooflight and reaching the opposite side. At the same time, 6,500 lux was recorded outside the south window of the 5th floor and 5,000 lux outside the window on the north side. Outside the 4th floor level, under the projection floor above, 5,900 lux were measured on the south and 5,000 lux on the north. The outside measurements indicate the impact of the 5th floor´s projection in reducing daylight ingress to the 4th floor studios and, although at this level illuminance values are reasonably high near the windows, with 600 lux being measured near the south side window and 500 lux near the north side one, daylight decreases significantly towards the middle of the floor, where 160 lux were recorded.

Overall, whilst all across the 5th floor adequate illuminance levels were measured, the rooflights of the 5th floor, coupled with the mezzanine configuration, were not effective in bringing sufficient daylight into all parts of the 4th floor, especially in an overcast sky autumn day. On the other hand, in parallel to the measurements, a survey conducted on the users of the space during the spot measurements revealed that only 10% of the students found daylighting levels insufficient. The measurements showed the potential risk of excessive illuminance levels during summer days on the 5th floor, without the use of the internal blinds, and insufficient daylight levels during winter on the 4th floor. This underscores the importance of the movable controls of daylight and sunlight coming from the rooflights in the summer and complementary task lighting in the winter.

The climate and sky of London

According to the Koppen Climate Classification, London (latitude 51.5° N) has a Temperate Oceanic Climate (Cfb), (Peel; Finlayson, 2015). Based on the weather fie from Meteonorm 8.0 (METEONORM [...], 2021), annually, the average minimum air temperature in winter and average maximum in the summer vary from 4°C to 23°C, respectively. Typical summer days have partly cloudy sky, whilst winter days are mostly cloudy. The sky of London, famous for its rainy and overcast days, has a significant variation in the average percentage of sky cover throughout the year, with an annual frequency of cloudy sky of more than 50%. The months of November and December have only 10% of sunny sky and about 19% partly cloudy conditions, while August has up to 35% of sunny sky and 10% partly cloudy conditions. Future climate scenarios show that in 2050 the frequency of cloudy sky will drop especially during summer.

Consequently, radiation levels are predicted to get higher in this period, accompanied by an increase in temperatures throughout the year and in the daylight availability, with global illuminance levels varying from 54 klux in May, 57 klux in June and July and 54 in August, at 12 o'clock in the current scenario, to 58 klux in May and July, 59 klux in June and 61 klux in August, (Figure 6), representing an increment of around 12% in illuminance levels in August, being this the most extreme case for the future scenario (Meteonorm 8.0. Meteotest). Regarding solar altitudes, during the summer solstice the sun is at approximately 62o high at 12h in London, 39o in the equinox and 15o in the winter solstice, respectively. The reasonably low solar altitudes, particularly in the summer morning and evening, pose the risk of discomfort and disability glare on clear sky days in London.

Methodology

For this study a series of complementary analytical daylighting performance assessments were undertaken by using computer simulations, to critically examine the daylight conditions of various spaces within the Marylebone building.

The daylighting assessments were carried out for each floor of the building, considering the current occupancy scenario. The digital modelling of the building was built with the software Rhinoceros 5 (RHINOCEROS [...], 2015). At first, the daylighting simulations were performed with the software DIVA 4.0 (SOLEMMA, 2016), which is a simulation tool that embodies the calculation methods from the daylighting software, Radiance (RADIANCE [...], 1994), which accounts for diffuse and direct radiation, the sky component, as well as external and internal reflections. After its discontinuation, the simulations were redone using the software ClimateStudio (SOLEMMA, 2018), which substituted DIVA as its new and more accurate, updated version.

Figure 6 - (top) Daily Average Global Illuminance for current climate, and (bottom) future climate of London (based on the weather file from Meteonorm 8.0 (METEONORM [...], 2021),

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	1	3	1	0	0	0	0	0
6	0	0	0	2	8	11	9	4	0	0	0	0
7	0	0	0	10	20	21	19	14	6	0	0	0
8	0	0	8	20	32	30	30	26	16	7	1	0
9	1	6	17	29	42	39	40	36	26	15	6	1
10	7	13	23	38	52	49	46	46	34	21	11	6
11	11	19	28	44	59	53	54	54	39	27	15	9
12	12	21	33	49	54	57	57	54	43	28	17	11
13	13	22	34	48	55	60	57	54	41	28	18	12
14	14	23	34	44	51	57	56	52	38	29	15	11
15	10	17	28	38	46	48	49	45	33	22	10	6
16	4	11	20	28	37	38	38	35	25	13	3	1
17	0	3	12	19	25	29	31	25	16	4	0	0
18	0	0	3	9	16	19	21	15	5	0	0	0
19	0	0	0	2	7	10	11	5	0	0	0	0
20	0	0	0	0	1	3	3	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

Daily Average Global Illuminance
(klux)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	1	3	1	0	0	0	0	0
6	0	0	0	1	8	11	9	4	0	0	0	0
7	0	0	0	10	20	21	19	14	7	0	0	0
8	0	0	8	20	34	32	28	26	17	8	1	0
9	1	6	15	30	47	42	38	37	27	16	5	1
10	6	13	23	40	57	51	49	49	36	24	10	5
11	10	19	28	47	64	57	57	58	44	30	15	9
12	12	23	33	50	58	59	58	61	46	32	18	11
13	12	23	33	50	59	60	59	60	48	30	18	10
14	14	21	34	45	51	57	60	56	44	26	17	11
15	9	16	29	39	45	52	54	50	36	19	10	7
16	3	10	20	30	36	45	47	40	27	11	4	1
17	0	3	11	20	27	34	36	28	16	3	0	0
18	0	0	3	9	16	23	24	17	5	0	0	0
19	0	0	0	1	7	12	12	6	0	0	0	0
20	0	0	0	0	0	4	3	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

Daily Average Global Illuminance
(klux)

Source: the authors.

As shown in the work of Nabil and Mardaljevic (2006), values of DF, DA and UDI were simulated, aiming for a detailed understanding of the daylighting performance in the building. However, for the purpose of this technical study, only values of UDI and DF are presented and discussed. Whilst the UDI shows the annual daylight performance of an internal space, in a specific climatic context, the DF provides a general notion of the daylighting performance of the space, mainly expressing the relationship between aperture and sky view factor. It is worth mentioning that the DF is a performance metric still adopted today by international organizations, such as CIBSE and BREEAM in the UK.

On the other hand, the Daylight Autonomy (DA), contemplated within the concept of UDI, presented information potentially repetitive for this specific study, especially since the focus is on visual comfort rather than on energy saving strategies. The DF and UDI simulations were followed by the assessment of glare probability.

The daylight simulations were done for all 6 floors of the building, at the working-height plane of 0.75 meters, on a 1 by 1m grid, following the guidelines for daylight simulations of classrooms defined by Larsen (2004). To the purpose of this study, the discussion addresses the results from the 2nd, 4th, 5th and 6th floors only, excluding the first and ground level, as they have different room layouts from the above and are not part of the School of Architecture. For the 5th floor, the analysis tested the effect of the existing internal blinds on the south rooflights (in terms of illuminance levels and glare probability in the studio) as well as of the hypothetical proposed blinds suggested for the south-facing ribbon windows. Simulation scenarios considered the effect of these blinds combined and separately (More information about the digital model and the specifications of the physical-material properties used in the simulations are presented in the Appendix).

The simulation results were initially assessed based on the minimum requirement of 2% DF, alongside the uniformity ratio of 80% of the floor plan with the 2% DF, set for educational spaces by BREEAM (2011). In addition, the adopted performance criterion for UDI was based on the work of Mardaljevic *et al.* (2012), which considers the range between 300 and 3000 lux as satisfactory Illuminance levels, between 100 and 300 as in need of complementation with artificial lighting, below 100 as insufficient and above 3000 lux as exceeding comfort levels and with a high risk of glare.

Glare Simulations were carried out for the 5th floor, with a special focus on characterizing the combined effect of the rooflights facing north and south orientations upon the interior spaces, considering the original and current layouts and furniture. Because of the different types of activities (drawing tables versus the use of the computer) and the equipment and furniture associated with them, it was particularly important for the assessment of glare to look at the original and current forms of occupation in the studio spaces. Glare simulations were carried out using *annual glare* simulations, which are calculated at the eye level. The respective results were generated for the whole year on a grid of 1m distance between nodes, with 8 view directions at 1.2m high.

Point-in-time results were also generated for the glare analysis for one specific view for the summer and winter solstices and the spring equinox, at 9h, 12h and 16h. Results were presented in the form of false colour images and Daylight Glare Probability (DGP) renders (created in Climate Studio) with highlighted high luminance areas of above 2000 cd/m^2. The 6th floor was not included in these studies since its rooflights face north, maximizing the penetration of diffuse light, rather than direct, therefore, posing a low glare risk. For the purpose of this technical study, the UDI, DF and illuminance simulations results are presented only with the current layout. However, for the glare studies, both layouts are analysed and discussed.

The climatic data bank file for London, available in Meteonorm 8.0 (METEONORM [...], 2021), was adopted for all simulations. For the DF and Illuminance simulations, the Overcast Sky (CIE) was used, as this is the predominant London sky condition.

Daylight performance simulations

UDI and DF: results and discussion

The simulations of DF and UDI for the 2nd, 4th, 5th and 6th floors, indicated that, in general, and as expected, the same window-to-wall ratio (WWR) on both main facades of the case-study building results in a better daylight performance on the south side. Results are presented in Figure 8.

On the 4th, 5th and 6th floors, daylight enters from both the north and south facades, reaching the middle of the plan, but producing varying results. For the 4th and 6th floors the middle of the floor plan reaches good levels of UDI (ranging from 70 to 50% respectively), but for the 5th floor, especially in the south, the values are lower due to excessive illuminance. On the other hand, on the 2nd floor, the corridors are poorly daylit, especially where internal partitions are opaque, and the impact of external obstructions, particularly on the south side, also affects the results being supplemental and insufficient in some areas.

The DF results indicate higher values near the windows on both facades on the 2nd floor, around 6-13% DF on the south side and 5-12% DF on the north, with values decreasing rapidly towards the centre of the plan to close to 1% near the interior walls and close to 0% in the corridors. In this scenario, the minimum DF of 2% required for educational spaces (BREEAM, 2011) is not achieved everywhere in the classrooms. On the 4th floor, high values of DF were found in specific areas, due to the light penetration coming from the rooflights on the 5th floor. The 4th floor has also the lowest mean DF of 1.7%, whereas in the 2nd floor classrooms the mean DF varies between 2% and 3%, which can be explained by the overshadowing impact of the 5th floor mezzanine, projected by 3.50 metres over the floors below (Figure 8). Due to the presence of the rooflights, the 5th floor has the highest DF, with a mean value of 11.4% and a maximum of 23.6%. On the 6th floor, the saw-tooth roof-lights produced a mean DF of 9.5%, which is lower than the 5th floor but higher than the 2nd and 4th floors.

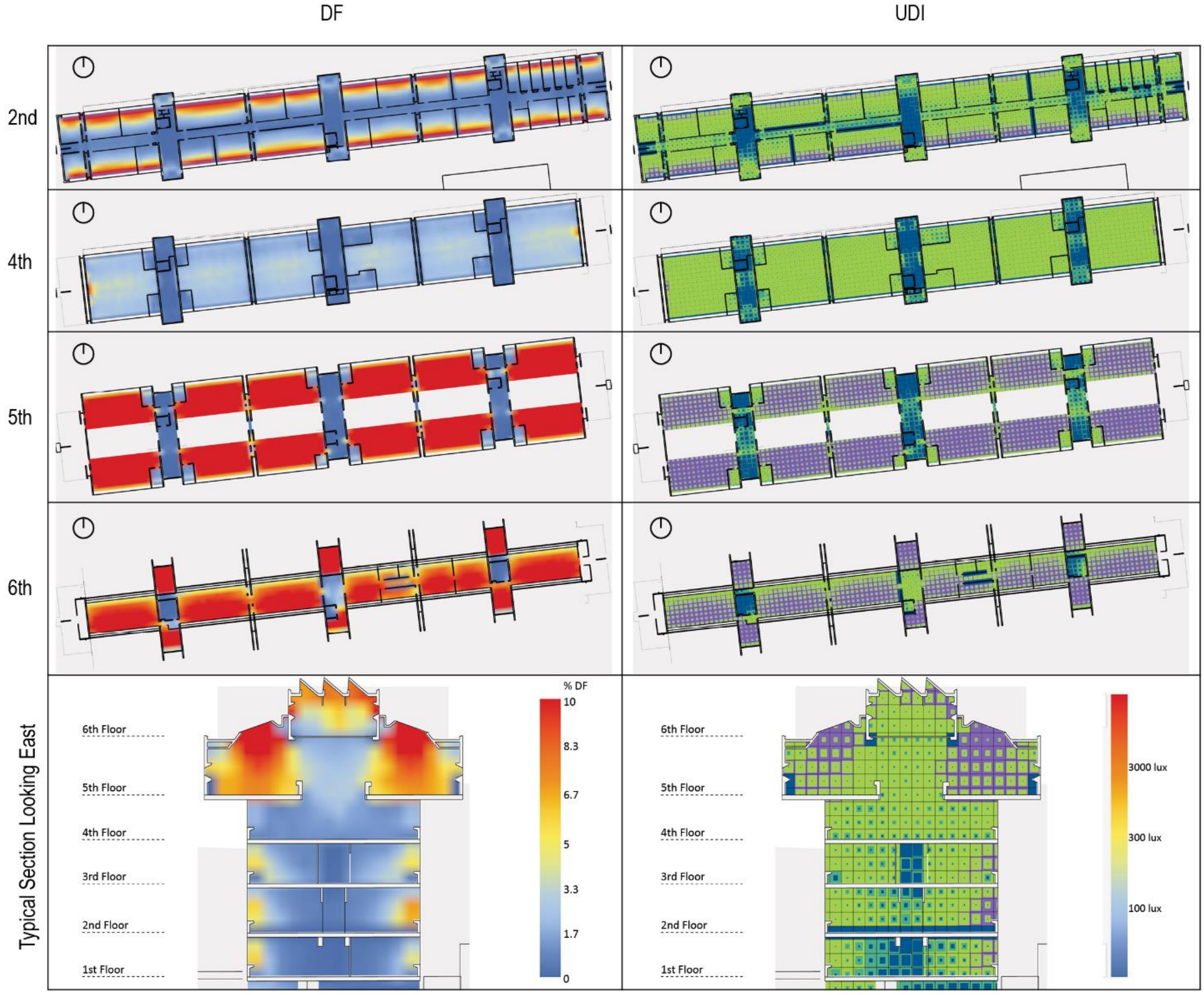
Regarding uniformity, the criterion of a minimum of 2% DF in at least 80% of the floor area was not met in most of the smaller rooms on all floors. However, the studios located on the upper floors (4th, 5th, and 6th floors) mostly achieved the target. This requirement only applies to regularly occupied spaces; therefore, corridors and vertical circulation were not considered in the percentage calculation.

Looking at the UDI results, on the 2nd floor classrooms on the north side have values between 60 and 90%. Respectively, the south-facing classrooms have 40 to 70% UDI, with lower values in areas closer to the windows and corridors which are excessive UDI. Where there are opaque partitions, especially when positioned on the south side, values get substantially lower in the corridors, below 10%, which configures supplement and failing UDI. However, where glass partitions are utilised UDI is around 50% in the corridors, being acceptable and supplemental UDI. On the 4th floor, following the pattern seen for the DF simulations, the UDI results also show a rather uniform pattern in the open plan areas, with values between 65 and 83% throughout the area, although there are some lower values between 50-60% scattered closer to the north facade and in the middle of the plan. The south facing rooms have UDI values between 50 and 80%, with higher values closer to the windows, whilst the north side ones have a poorer performance, with UDI between 20 and 60%.

The same pattern is observed on the 5th floor, with UDI results similar to the DF pattern, forming ellipsoid shapes in the middle of the plan. However, in contrast to the DF simulations, these ellipsoid forms contain the lowest performance factors of UDI, acceptable and excessive UDI, with figures between 25 to 45% on the south side and 40 to 70% on the north. The highest UDI values are concentrated close to the windows and on the north edge of the mezzanine. The small cellular offices on the south side show results of 30 to 75%, with acceptable and supplemental UDI. The north side rooms have a similar configuration with lower percentages around 45% UDI, mostly supplement and failing UDI, but higher values up to 80% close to the windows.

On the 6th floor, the UDI simulations also have a similar pattern to the DF simulations, with the same half-ellipsoid shapes in each sector of the plan. Similar to the 5th floor, lower values of UDI are represented by those shapes, with acceptable and excessive UDI marking between 40 to 70%, and higher values towards the edges of the plan, around 70 to 90%. On the south side, in the smaller rooms, acceptable and excessive UDI between 45 and 70% was identified, increasing to around 90% acceptable UDI in the rooms on the north side of the plan.

Figure 8 - DF and UDI results for the 3rd, 4th, 5th, and 6th floors of the Marylebone building, shown in plan and section

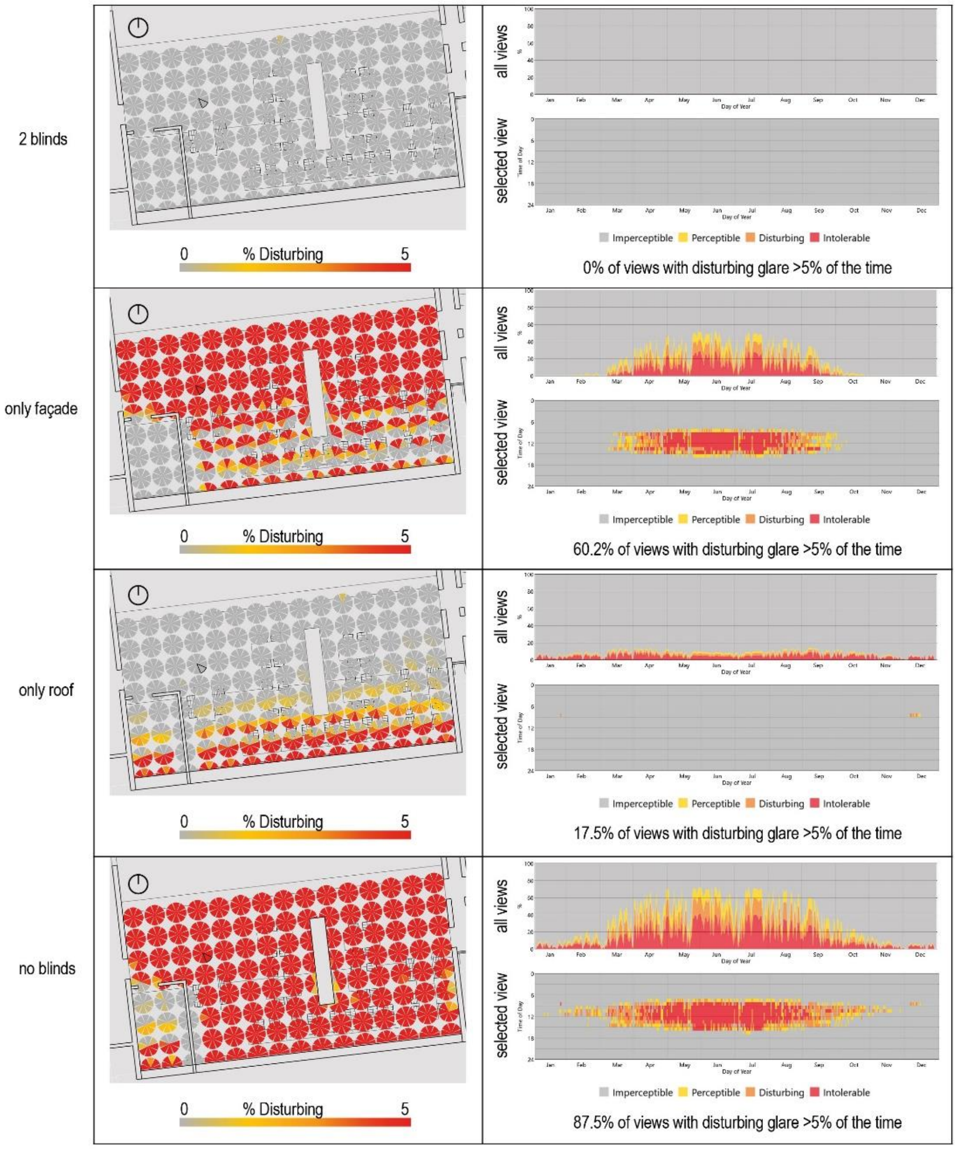


Source: the authors.

Daylight glare probability: results and discussion

The results from the daylighting simulations previously presented indicated reasonably high illuminance levels on the top floors, mainly in the areas influenced by the rooflights. For this reason, the assessment of glare probability was conducted on the 5th floor. As explained in the Methodology, for this specific part of the study, the layout and furniture from the original and current occupation scenarios were simulated and compared. The final results for annual glare are shown in the form of temporal charts and 8-view pie slices for every point in the grid (Figure 9). For point-in-time glare, interior fisheye views of the space are shown, which are similar to the field of view of the human eyes (Figures 10-12). The selected view for these simulations is shown in Figure 9 as the highlighted pie slice.

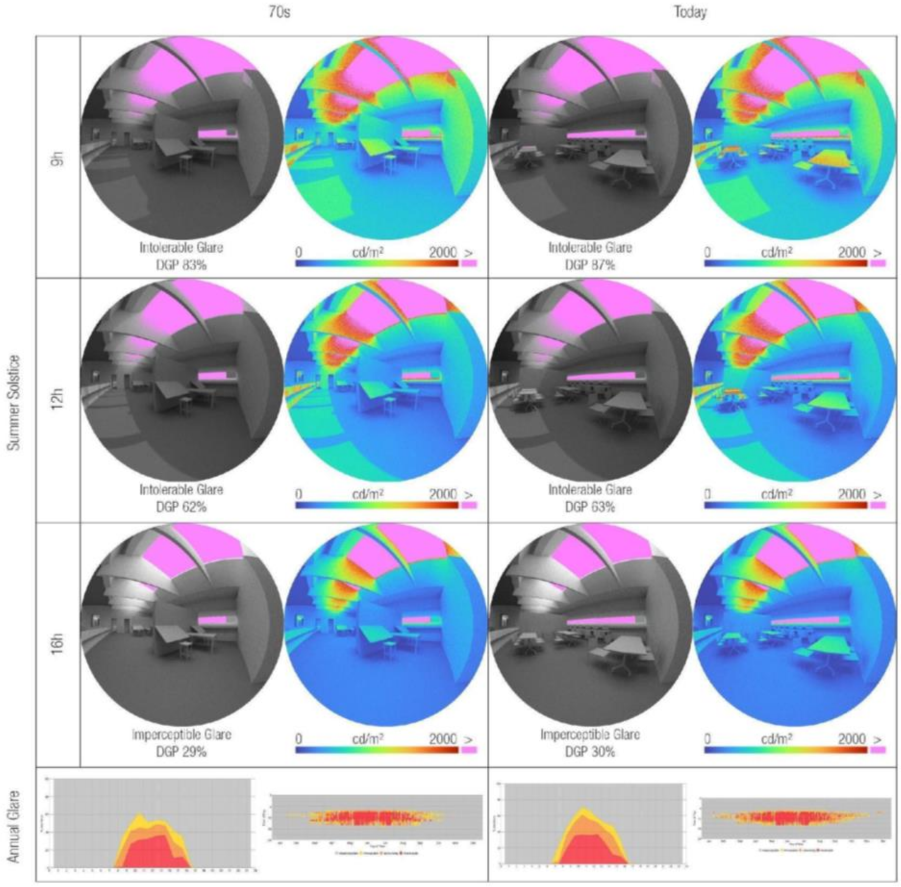
Figure 9 – Annual Glare simulations for current layout of the 5th floor studios in the Marylebone building with the use of blinds, selected view highlighted



Source: the authors.

The glare probability studies for the summer solstice (Figure 10) indicate that in the original 1970s layout with the drawing tables, the highest luminance values are caused by the rooflights and façade windows. At 9 am, the fisheye view indicates intolerable glare with 83%-87% of Daylight Glare Probability (DGP), where and when the user would be receiving direct sunlight from the rooflights. At 12pm, there is still intolerable glare on the fisheye view for both layouts (62-63% DGP). At 4 pm, the DGP values drop drastically, showing imperceptible glare for both layouts, being 29 and 30% for the fisheye views in the original and current layout, respectively. The high glare probability, especially at 9 am and 12 pm, can also be confirmed by the high luminance (cd/m²) values and lux levels, and appears in the outcome of annual glare, highlighting DGP levels from 8 am to 3 pm in the summer period (May to middle of August).

Figure 10 – Glare simulations for the 5th floor studios in Marylebone Building, in the summer solstice at 9h, 12h and 16h and annual glare



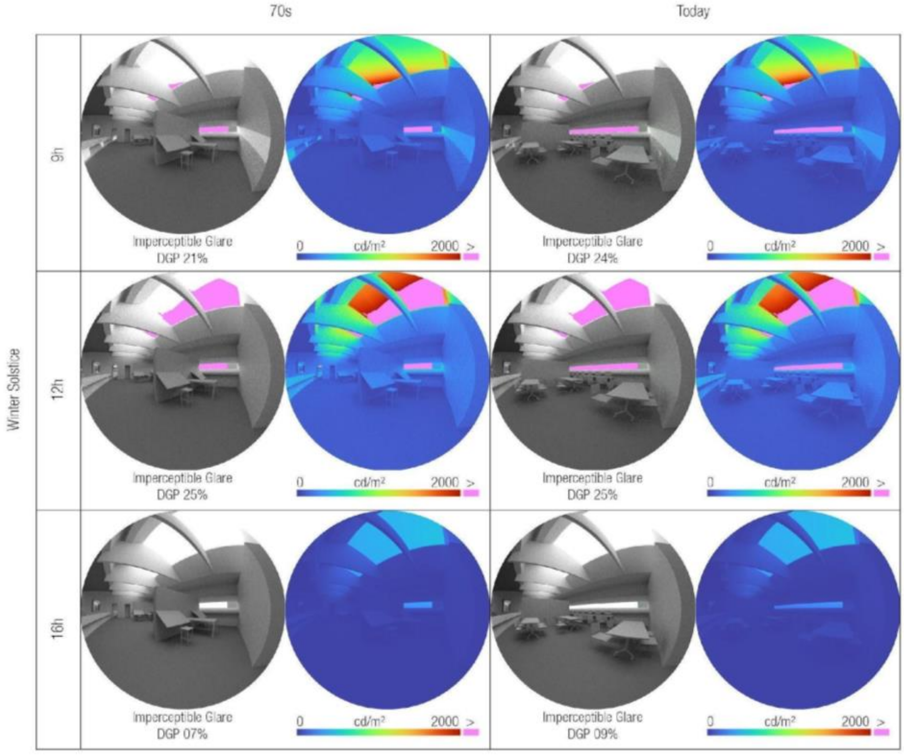
Source: the authors.

During winter solstice (Figure 11), the rooflights are not such an issue, with DGP values between 21 to 24% at 9 am in the fisheye view in both the original and current layouts, while the façade windows show the main source of luminance and high contrast DGP. At 12pm, DGP on the fisheye views goes up to 25%, still categorized as imperceptible glare DGP. At 4 pm, the values drop to 7-8% on the fisheye. At this point, it is worth mentioning that, apart from the low DGP simulated for the winter solstice, the problem of glare was observed as originating from the south-facing ribbon windows (Figure 5), causing disability glare due to low solar altitudes. The annual glare for this time of the year also indicates high DGP values in some mornings of the winter months, around 9 to 10 am, between November and January.

During the equinox (Figure 12), high contrast was found at 9 am, with luminance values up to 2000 cd/m² alongside the windows. DGP values are around 23 to 45% on all scenes at all hours, characterizing disturbing glare in the mornings and imperceptible glare in the afternoons. The annual glare simulation reveals high DGP levels at the equinox, from 9 am to 1 pm.

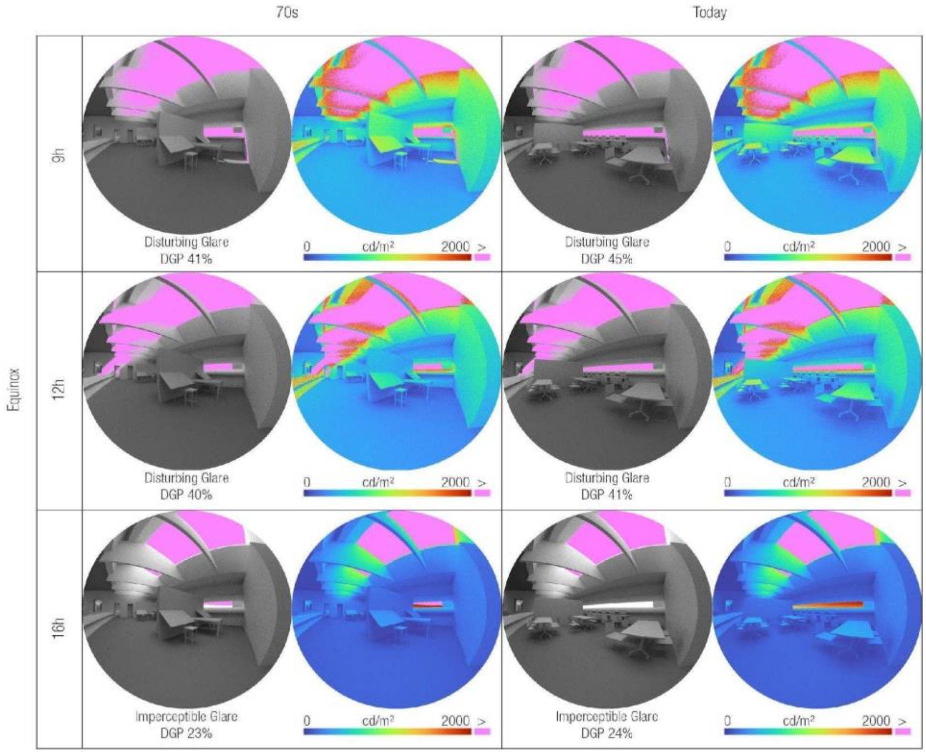
From these results, it can be stated that the change from clear to green-tinted glass was not an effective measure to avoid the risk of glare on the top floors.

Figure 11 – Glare simulations for the 5th floor studios in the Marylebone building, in the winter solstice at 9h, 12h and 16h



Source: the authors.

Figure 12 – Glare simulations for the 5th floor studios in the Marylebone building, in the winter solstice at 9h, 12h and 16h



Source: the authors.

The effect of the internal blinds was also tested for the current layout to evaluate if its use could improve results. It was found that the use of the roof and façade blinds combined can reduce DGP levels to 0% at all points of the grid. The use of the south-facing window blinds alone can decrease the proportion of views with disturbing glare above 5% of the time from 87.5% to 60.2%, reaching especially those points closer to and facing the façade (as it is the case for those occupants using the desk-top computers). In this case, the use of the roof blinds alone can decrease DGP from 87.5% to 17.5%, affecting a broader range of views along the floor plan.

Conclusion

The analytical studies presented here proved that the Marylebone building contains architectural features that enhance daylighting performance and visual comfort, commonly seen in modernist buildings of its time, particularly in temperate climates, where daylight availability is an issue during the cooler period of the year, typical of overcast sky. The rooflights, the horizontal long windows and the double height space are key examples of these features. Through this analytical work it was seen how the mezzanines between 4th and 5th floors not only improve spatial and visual quality by creating double-height spaces, but also allow top light from the north and south orientations to reach the central areas of the lower floors.

Overall, the daylight simulations revealed that satisfactory values of UDI can be achieved on the north side of the plan at the lower-level floors (affected mainly by diffuse light), whilst the south side (with diffuse and direct radiation) will need shading to reach high UDI levels near the facade. On the second floor, the glass partitions along the central corridor proved to make a significant difference in increasing lighting levels across the plan, especially when positioned on the south side, despite the shading effect created by the protruding top floors. Nevertheless, the south-side classrooms have lower UDI percentages than the north, as a result of levels above the maximum threshold of 3000 lux, pointing out the risk of glare. The 4th, 5th, and 6th floors UDI values are lower on the central areas of the plan, due to the influence by the rooflights and solar penetration, but DF values are more evenly distributed. The excessive lighting levels on the south side of the floor-plans and on the top floors exposed to the skylights highlight the risk of glare and raise questions about the efficacy of the symmetrical approach to the design of the rooflights and fenestration in general.

By deploying Climate-Based Daylight Modelling (CBDM), it was possible to identify daylight conditions across the floor plans during periods of partial and clear sky, when excessive illuminance levels were found. In this way, the analysis shows the risk and quantified the negative impact of adopting the symmetrical skylight (suitable for maximizing daylight penetration during overcast conditions), originally without any kind of control over the impinging solar radiation. In other words, this analytical work exposes the problems of designing exclusively for the predominant overcast conditions.

The glare problems identified on the 5th floor were also the result of the position of worktables and computers close and facing the south windows. Through the analytical work it was seen that the lower solar angles on winter days can aggravate this issue, even though simulations predicted lower DGP values. In this respect, the existing green glass (applied in the latest refurbishment) proved not to be effective against the risk of glare on the south side. This was less likely to be an issue in the original layout from the 70's, when drawing tables were used instead of computers, located in a different position more distant from the perimeter windows and at a tilted angle from the vertical illuminance. In fact, the glare on the 5th floor is not only caused by the south-facing windows, but also by the roof lights. However, it was verified that when the internal blinds also added in the latest refurbishment are pulled down, the focal area of contrast is restricted to the windows on the south facade.

Looking in-depth at the contribution of this analytical study, the glare simulations show that in the original occupation of 1970s, the layout in higher and lower floors offered more visually comfortable conditions that the contemporary layout, and could be used as a reference for today's occupation, indicating adequate positions of workspaces across the different floorplans. Other recommendations that can be extracted from the daylight simulations is the adoption of an open layout on the lower floors, to improve daylight distribution. In addition, the use of blinds, already previously incorporated to the rooflights, should be extended to the south facade windows, from which a higher risk of glare was identified.

Despite the verified excessive levels of daylight in specific areas of the top floors and the associated risk of glare (without the control of internal blinds), it is possible to say that the design approach to daylight adopted in the Marylebone building, in a time where there were no advanced simulations tools, proved to be successful in achieving daylight access into the spaces. Hence, much can be learnt from the architectural features and daylighting strategies adopted in this architectural design, with special consideration to the positioning of rooflights, however, calling the attention to the importance of adaptable control of illuminance level in the temperate climate, despite the predominant overcast conditions.

Regarding future research, possible next steps towards designing educational spaces with daylight in the temperate climate, are the analytical examination of adequate glazing ratios to different orientations and the design of skylights, aiming for high ranges of UDI (equal or above 80%), complemented by a study of dynamic control of excessive irradiation levels to eliminate glare risk.

Acknowledgements

Thanks to FAPESP - Fundação de Amparo à Pesquisa no Estado de São Paulo (process no.: 17/08451-2), for supporting this work. Thanks also to Amedeo Scofone for his technical advice. The authors are indebted to the advice from the late colleague, Benson Lau, remembered dearly for his passion for daylighting and modernist architecture.

References

ABBOTT, J. **A Guide to Modernism in Metro-land**. London: Unbound, 2020. 144 p.

ALEEM, B.; MUNIR, A.; VAN, C. **Case study evaluation of the Marylebone Campus:** Technical Report for Evaluation of Built Environments Module (7AEVD002W), University of Westminster 2016-17. London: University of Westminster, 2017. (Architecture and Environmental Design, Master Course. School of Architecture and Cities. Restricted access).

AL-OBAIDI, K. M.; ISMAIL, M. B.; ABDUL RAHMAN, A. M. A study of the impact of environmental loads that penetrate a passive skylight roofing system in Malaysian buildings. **Frontiers of Architectural Research**, v. 3, n. 2, p. 178-191, June 2014. DOI: https://doi.org/10.1016/j.foar.2014.03.004.

AL-SALLAL, K. A.; ABOUELHAMD, A. R.; DALMOUK, M. B. Daylighting performance in UAE traditional buildings used as museums. **International Journal of Low-Carbon Technologies**, v. 13, n. 2, p. 116–12118, June 2018. DOI: https://doi.org/10.1093/ijlct/cty003.

ANDERSEN, M. Unweaving the human response in daylighting design. **Building and Environment**, v. 91, p. 101-117, Sept. 2015. DOI: https://doi.org/10.1016/j.buildenv.2015.03.014.

ANDERSEN, M.; GOCHENOUR, S. J.; LOCKLEY, S. Modelling 'non-visual' effects of daylighting in a residential environment. **Building and Environment**, v. 70, p. 138-149, Dec. 2013. DOI: https://doi.org/10.1016/j.buildenv.2013.08.018.

BAKER, N.; STEEMERS, K. **Daylight Design of Buildings:** A Handbook for Architects and Engineers. London: James & James, 2002. 250 p.

BONE, K. **Lessons from Modernism**: Environmental Design Strategies in Architecture 1925-1970. New York: The Monacelli, 2014. 224 p.

BREEAM. **BREEAM New Construction.** 2011. Disponível em: https://breeam.com/standards/new-construction. Acesso em: 20 jun. 2019.

BREEAM. **Health and Wellbeing**: Hea 01 Visual Comfort. 2018. Disponível em: https://kb.breeam.com/section/new-construction/uk/2011/02-health-and-wellbeing/hea-01-visual-comfort/. Acesso em: 08 jan. 2021.

GONÇALVES, J. C. S.; MÜLFARTH, R. C. K.; MICHALSKI, R. L. X. N.; SHIMOMURA, A. R. P.; ROMÉRO, M. A.; FURUYAMA, C. M. S.; PINHO, J. K. C.; LIMA, E. G.; CARUNCHIO, C. F.; SEGOCIA, S. T.; SANTOS, K. D. As condições ambientais do edifício Vilanova Artigas, sede da FAUUSP em São Paulo: estudos analíticos. **PARC: Pesquisa em Arquitetura e Construção**, Campinas, SP, v. 13, p. e022001, jan. 2022. DOI: http://dx.doi.org/10.20396/parc.v13i00.8661881.

HOSSAIN, M., WENG, Z.; SCHIANO-PHAN, R.; SCOTT, D.; LAU, B. Application of IoT and BEMS to Visualise the Environmental Performance of an Educational Building. **Energies**, v. 13, n. 5, p. 4009, Aug. 2020. DOI: https://doi.org/10.3390/en13154009.

IES. ILLUMINATING ENGINEERING SOCIETY. **Glare**. 2023. Disponível em: https://www.ies.org/definitions/glare/ Acesso em: 10 ago. 2024.

JAKUBIEC, J.; REINHART, C. DIVA 2.0: Integrating daylight and thermal simulations using Rhinoceros 3D, Daysim and Energyplus. *In*: CONFERENCE OF INTERNATIONAL BUILDING PERFORMANCE SIMULATION, 12., 2011, Sydney. **Proceedings [...].** Sydney: IBPSA, 2011. Disponível em: https://publications.ibpsa.org/proceedings/bs/2011/papers/bs2011_1701.pdf. Acesso em: 20 mar. 20224.

KONIS, K. S. A novel circadian daylight metric for building design and evaluation. **Building and Environment**, v. 113, p. 22-38., Feb. 2017. DOI: https://doi.org/10.1016/j.buildenv.2016.11.025.

LARSEN, K. **Daylight availability in classrooms:** A simulation study. 2004. Tese (Doutorado) - Department of Building Technology and Structural Engineering, Aalborg University, Aalborg. 2004.

LAU, B. 338: The Poetics of Sacred Light – A Comparative Study of the Luminous Environment in Ronchamp Chapel and the Church in the Monastery of La Tourette. *In*: CONFERENCE ON PASSIVE AND LOW ENERGY ARCHITECTURE, 25., 2008, Dublin. **Proceedings [...].** Dublin: PLEA, 2008.

LECARO, M.; LAU, B.; RODRIGUES, L.; JARMAN, D. The application of vernacular Australian environmental design principles in Glenn Murcutt's architecture. **Future Cities and Environment,** v. 3, n. 3, Apr. 2017. DOI: https://doi.org/10.1186/s40984-017-0026-6.

LEWIS, A. The mathematisation of daylighting: a history of British architects' use of the daylight factor. **The Journal of Architecture**, v. 22, n. 7, p. 1155-1177, Sept. 2017. DOI: https://doi.org/10.1080/13602365.2017.1376342.

LIMA, K. M.; BRUGNERA, R. R.; CARAM, R.M. O potencial de brises dinâmicos em escritórios quanto ao uso de energia em climas tropicais. *In*: ENCONTRO NACIONAL, 13.; IX ENCONTRO LATINO-AMERICANO DE CONFORTO NO AMBIENTE CONSTRUÍDO, 9., 2015, Campinas. **Anais [...].** Campinas: ENCAC, 2015.

MARCONDES CAVALERI, M. P., CUNHA, G.R.M., GONÇALVES, J.C.S. Iluminação natural em edifícios de escritórios: avaliação dinâmica de desempenho para São Paulo. **PARC: Pesquisa em Arquitetura e Construção**, Campinas, SP, v. 9, n. 1, p. 19-34, mar. 2018. DOI: https://doi.org/10.20396/parc.v9i1.8650725.

MARDALJEVIC, J.; ANDERSEN, M.; ROY, N.; CHRISTOFFERSEN, J. Daylighting metrics: is there a relation between useful daylight illuminance and daylight glare probability? *In*: BUILDING SIMULATION AND OPTIMIZATION CONFERENCE, 2012, Loughborough. **Proceedings [...].** Loughborough: IBPSA, 2012. Disponível em: https://publications.ibpsa.org/conference/paper/?id=bso2012_3B1. Acesso em: 10 jun. 2024.

MARZOUK, M.; ELSHARKAWY, M.; MAHMOUD, A. Optimizing daylight utilization of flat skylights in heritage buildings, **Journal of Advanced Research**, v. 37, p. 133-145, Mar. 2022. DOI: https://doi.org/10.1016/j.jare.2021.06.005.

METEONORM versão 8. Meteotest. Climate data. Berna: Meteotest, 2021. Disponível em: https://meteonorm.com/en/meteonorm-version-8. Acesso em: 11 jan. 2021.

MOON, P.; SPENCER, D. E. Illumination from a non-uniform sky. **Illuminating Engineer,** v. 37, p. 707-726, Jan. 1942.

MOORE, F. **Concepts and Practices of Architectural Daylighting**. New York: Van Nostrand Reinhold, 1991. 290 p.

NABIL, A.; MARDALJEVIC, J. Useful daylight illuminance: a new paradigm for assessing daylight in buildings. **Lighting Research & Technology**, v. 37, n. 1, p. 41-59, Mar. 2005. DOI: https://doi.org/10.1191/1365782805li128o.

NABIL, A.; MARDALJEVIC, J. Useful daylight illuminances: A replacement for daylight factors. **Energy and Buildings,** v. 38, n. 7, p. 905-913, July 2006. DOI: https://doi.org/10.1016/j.enbuild.2006.03.013.

PEEL, M. C.; FINLAYSON, B. L.; MCMAHON, T. A. **Update** World Map of Koppen-Geiger climate Classification. **Hydrology and Earth System Sciences**, v. 11, p. 1633-1644, 2007. DOI: https://doi.org/10.5194/hess-11-1633-2007.

PHILLIPS, D. **Daylighting: natural light in architecture**. Oxford: Architectural, 2004. 212 p.

PIERSON, C.; WIENOLD, J; BODART, M. Review of Factors Influencing Discomfort Glare Perception from Daylight. **LEUKOS**, v. 14, n. 3, p. 111-148, Feb. 2018. DOI: https://doi.org/10.1080/15502724.2018.1428617.

RADIANCE: a validated lighting simulation tool. 2019. Disponível em: https://www.radiance-online.org/. Acesso em: 20 jun. 2024.

REINHART, C. F.; MARDALJEVIC, J.; ROGERS, Z. Dynamic Daylight Performance Metrics for Sustainable Building Design. **Leukos**, v. 3, n. 1, p. 7-31, Sept. 2006. DOI: https://doi.org/10.1582/LEUKOS.2006.03.01.001.

REINHART, C.; HERKEL, S. The Simulation of annual daylight illuminance distributions – a state-of-the-art comparison of six RADIANCE-based methods. **Energy and Buildings**, v. 32, n. 2, p. 167-187, July 2000. DOI: https://doi.org/10.1016/S0378-7788(00)00042-6.

RHINOCEROS: design, model, present, analyse, realize. 5.0. Seattle: Robert McNeel, 2015. Disponível em: https://www.rhino3d.com/5/. Acesso em: 20 jan. 2024.

RIBA. ROYAL INSTITUTE OF BRISTISH ARCHITECTS. **Modernism in Architecture**. 2019. Disponível em: https://www.architecture.com/explore-architecture/modernism. Acesso em: 15 jun. 2019.

RUSSO, F. **Climatic Responsive Design in Brazilian Modern Architecture**. Dissertação (Mestrado) - Martin Centre for Architectural e Urban Studies, Cambridge University, Cambridge, 2004.

SANCHEZ JAIME, A. C.; LAU, B. Light in Seinäjoki Library, Rovaniemi Library and Mount Angel Library designed by Alvar Aalto- Critical Review. *In*: CONFERENCE ON SUSTAINABLE ARCHITECTURE + URBAN DESIGN, 28., 2012, Lima. **Proceedings [...].** Lima: PLEA, 2012.

SCHIANO-PHAN, R.; LAU, B.; POUREL, D.; KHAN, S. 'Spatial Delight and Environmental Performance of Modernist Architecture in London – Golden Lane Estate'. **Future Cities and Environment,** v. 4, n. 1, p. 16, Sept. 2018. DOI: https://doi.org/10.5334/fce.47.

SOLEMMA. **ClimateStudio**: advanced daylihting, and thermal analisis. 2018. Disponível em: https://www.solemma.com/climatestudio. Acesso em: 20 jan. 2024.

SOLEMMA. **Diva for Rhino** 4.0. 2016. Disponível em: https://www.solemma.com/diva. Acesso em: 30 jan. 2024.

TAGLIABUE, L. C.; BUZZETTI, M.; AROSIO, B. Energy saving through the sun: analysis of visual comfort and energy consumption in office space. **Energy Procedia**, v. 30, p. 693-703, 2012. DOI: https://doi.org/10.1016/j.egypro.2012.11.079.

TREGENZA, P.; WILSON, M. P. **Daylighting: Architecture and Lighting Design**. London: Routledge, 2013. 290 p.

UCL. UNIVERSITY COLLEGE LONDON. **Survey of London**: University of Westminster, Marylebone Road Campus, 2017. Disponível em: https://blogs.ucl.ac.uk/survey-of-london/2017/09/01/university-of-westminster-marylebone-road-campus/. Acesso em: 15 out. 2019.

WANG, Q.; XU, H.; ZHANG, F.; WANG, Z. Influence of color temperature on comfort and preference for LED indoor lighting. **Optik**, v. 129, p. 21-29, Jan. 2017. DOI: https://doi.org/10.1016/j.ijleo.2016.10.049.

WIENOLD, J.; CHRISTOFFERSEN, J. Towards a new daylight glare rating. *In:* EUROPEAN LIGHING CONFERENCE – LUX EUROPA, 10., Berlin, 2005. **Proceedings [...].** Berlin: Ludwig Erhard Haus Industrie – und Handelskarmmer zu Berli, 2005. p. 157-161.

WIENOLD, J.; REETZ, C.; KUHN, T. E.; CHRISTOFFERSEN, J. Evalglare: a new RADIANCE-based tool to evaluate glare in office spaces. *In*: INTERNATIONAL RADIANCE WORKSHOP, 3., 2004, Fribourg. **Proceedings [...].** Fribourg: Ecole D'Ingénieurs et d' Architectes, 2004. Disponível em: https://www.radiance-online.org/community/workshops/2004-fribourg/presentations/Wienold_extabs.pdf. Acesso em: 20 jan. 2024.

ZHOU, Z., LAU, B. The Poetics of Light in the Extension of the Canova Sculpture Gallery by Carlo Scarpa. *In*: INTERNATIONAL CONFERENCE DESIGN TO THRIVE. 33., 2017, Edinburgh. **Proceedings [...].** Edinburgh: PLEA, 2017. v. 2, p. 3474.

Appendix

Making of the digital model

The three-dimensional digital model of the Marylebone building contains all floors of the building with the two possible layout scenarios, the original (from the 1970s) and the current, separated into different layers. Technical information about the plans, sections and the original layout were obtained from the University of Westminster Archives, whilst details about the current layout were obtained on-site. For the glare simulations on the 5th floor studios, furniture was modelled, both for the original and current layouts.

Physical materials' properties

The visual and solar control properties of the materials used in the simulation model were based on a mix of on-site observations, archival research, field measurements as well as calculations. The light transmittance and solar heat gains coefficient of the glazing modelled for the 5th and 6th floor rooflights and for the main glazing of the north and south facades below them were derived from the specifications issued by the architects during the refurbishment of 2012 and the observation of tinted solar control glass verified on-site. Based on this info, assumptions were made and a close match on the material database of the modelling software was found (see Table 1).

Table 1 – Materials properties for digital model (ClimateStudio default values)

	Transmittance (Tvis)	Reflectance (Total)	Reflectance (Diffuse)	Solar Heat Gain Coefficient (SHGC)
Rooflights	0.80	-	-	0.70
Vertical Glazing	0.70	-	-	0.46
Blinds	-	54.79	53.71%	-

Source: the authors.

To decide on the reflectance of the internal surfaces, the specifications available in the software's default material library were compared to those measured *in situ*. Measurements of the luminance of material surfaces were taken from samples of the internal surfaces, using a Luminance Meter, as shown in Figure 7. In order to calibrate the measurements and calculate the reflectance equation, measurements of a white and a grey card, with known reflectance values from the manufacturer (0.9 for the white card and 0.18 for the grey card), were taken prior to the measurements of the building's internal surfaces. For the calculation of the internal reflectance of walls (ρ being the reflectance of a surface subjected to diffuse illumination), ceiling and floor, the values obtained from the measurements were applied to the following equations (Baker; Steemers, 2002):

$$\rho_1 = \rho_{white} * \frac{L_{surface}}{L_{white}} \quad (1) \qquad \rho_2 = \rho_{grey} * \frac{L_{surface}}{L_{grey}} \quad (2) \qquad \rho_{hh} = \frac{\rho_1 + \rho_2}{2} \quad (3)$$

Where:

$\rho_{white} = white\ card's\ real\ reflectance$

$\rho_{grey} = grey\ card's\ real\ reflectance$

$L_{white} = white\ card's\ measured\ reflectance$

$L_{grey} = grey\ card's\ measured\ reflectance$

$L_{surface} = surface's\ measured\ reflectance$

$\rho_{hh} = hemispherical - hemispherical\ reflectance\ of\ materials$

Figure 7 - (left) Reflectance measurement method, (right) and luminance meter tool

Source: Sylvia Segovia.

The outcomes of the on-site measurements were: 0.80 for the ceiling, 0.38 for the floor and 0.75 for the walls. The results from the measurements were very similar to the values from the software's material library (DIVA) shown in Table 2, which were then selected to inform the digital model for the daylight performance simulations. For the 1970s model, the assumptions on the materials values were the same as the current buildings except for the light transmission and solar heat gain coefficient of the glazing, which were considered as 0.80 and 0.70 respectively.

Table 2 – Reflectance of materials present in the main workspaces of the Marylebone building (from DIVA and ClimateStudio)

	Walls	Ceilings	Floors	Furniture
DIVA and ClimateStudio default reflectance values	WhiteInteriorWalls_70 (0.7)	GenericCeiling_80 (0.8)	GenericFloor_20 (0.2)	GenericFurniture_50 (0.5)

Source: the authors.

1 **Sylvia Tavares Segovia**
Architect and Urbanist. MSc. Klaus Bode Consultancy. Postal address: Design District - Soames Walk, 13, London - UK. ZIP Code SE10 0AX.

2 **Rosa Schiano-Phan**
Architect. Reader. School of Architecture and Cities, University of Westminster. Postal address: Marylebone Road, 35, London - UK. NW1 5LS.

3 **Joana Carla Soares Gonçalves**
Architect and Urbanist. Associate Professor. The Bartlett School of Architecture, University College London. Postal address: Gordon Street, 22, London - Reino Unido. Zip Code WC1H 0QB

4 **Roberta Consentino Kronka Mulfarth**
Architect and Urbanist. Full Professor. Faculty of Architecture and Urbanism of the University of São Paulo. Postal address: Rua do Lago, 876, São Paulo, SP - Brasil. CEP 05508-080