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WELL CERTIFICATION AND CIRCADIAN LIGHTING: COMPARATIVE DAYLIGHT ANALYSIS OF OFFICE BUILDING TYPOLOGIES IN SÃO PAULO AND BERLIN

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Abstract: Circadian rhythms are internal processes that reflect the 24-hour solar day and enable organisms to adjust to changes in their environment across time. Mood problems frequently coincide with disturbances in circadian clock-regulated reactions, whereas disturbances in circadian rhythms are linked to jet lag, night-shift employment, or exposure to artificial light during nighttime hours. Contemporary lifestyle habits cause a disturbance in the natural sleep-wake cycle, leading to the development of many illnesses. Circadian disruption is included as one of the variables, along with smoking, food, exhaustion, sleep quality, increasing body mass index, and obesity. The insufficient duration of daylight and the excessive exposure to artificial light during nighttime have resulted in a disconnection between individuals and their surroundings, leading to the emergence of psychological issues. The aim of this research is to assess the circadian capabilities of three building models based on WELL Certification criteria, compare their daylight distribution, and provide design principles for promoting circadian rhythm and enhancing users' well-being in office buildings. The Adaptive Lighting for Alertness (ALFA) tool was employed to compute the Equivalent Melanopic Lux for the WELL Certification criterion within the given scenarios. The results suggest that implementing shallow office layouts could benefit users by fostering a regular circadian rhythm, as it promotes a consistent circadian cycle, leading to enhanced sleep quality, decreased stress levels, and reduced risk of developing severe illnesses.
Keywords: daylight; circadian rhythm; health; ALFA; WELL Certification

INTRODUCTION

Office workers spend most of their time indoors, resulting in a diminished exposure to daylight throughout their careers. Consequently, their reliance on artificial lighting, particularly during late hours, is heightened. The primary factor that influences circadian rhythms is exposure to light (Kantermann, 2013), particularly daylight (Figueiro; Nagare; Price, 2018). Modern lifestyles pattern leads to a disruption in people's circadian rhythm, resulting in several diseases. Foster (2020) points out that the short-term consequences of little daylight are: microsleep, irritability, concentration problems, lack of motivation and memory impairment. He also emphasizes that some long-term consequences are physiological and psychosocial stress, cardiovascular disease, increased use of stimulants and sedatives, and metabolic syndrome. According to Ticleanu (2020), circadian disruption is one of the factors raised, alongside smoking, diet, fatigue, and sleep quality, increased body mass index and obesity. Stevens and Rea (2001) proposed a link between light exposure at night, endocrine disruption, and breast cancer risk.

The evolution of our life pattern has been influenced by artificial resources, technology, globalization, and so forth. The advent of electric light yielded numerous advantages, such as the ability to prolong working hours past sunset. In the field of architecture and building design, many architects have tended to overlook the incorporation of daylight, largely influenced by the widespread use of electric lighting, particularly in the LED lighting era, where energy consumption and heat production from the artificial sources are minimal.

As technology advanced, people's stress levels also increased. The insufficient duration of daylight and the excessive exposure to artificial light during nighttime have resulted in a disconnection between individuals and their surroundings, leading to the above-mentioned issues. While the causes of stress can be diverse, it is important to also evaluate the impact of daylighting performance in buildings on life quality.

According to Jung et al. (2010), exposure to bright daylight exceeding 10,000 lux has been associated with a decrease in cortisol levels, the stress hormone. Additionally, exposure to daylight for at least three hours a day has been linked to a reduction in work stress and dissatisfaction (Alimoglu; Donmez, 2005 apud Ticleanu, 2020).

In a historical context, when daylight served as the primary source of indoor illumination, office buildings were purposefully designed to optimize its utilization. The importance of daylight is evident in the evolution of skyscraper design in Chicago and New York since the late 1800s. The quality and profitability of office spaces were intricately tied to the presence of large windows and high ceilings, facilitating maximum daylight penetration. As a result, the distance between windows and the innermost wall or public corridor, the office depth, was determined by the reach of daylight before the widespread use of fluorescent bulbs in the 1940s. The building design, therefore, followed an inside-out approach, starting from the smallest cell (the single office) to the full floor plan (Willis, 1995).

> The maximum of twenty to twenty-eight feet was almost universally observed and changed only slightly until the introduction of fluorescent lighting. What the industry called "economical depth" referred to the fact that shallow, better-lit space produced higher revenues than deep and therefore dark interiors (…) a 1923 survey of values in Boston showed that offices fifteen feet deep leased for $3.00 per square foot, while space twenty-five feet brought only $2.60, and fifty feet, only $1.65. Since the latter cost nearly as much to build and operate, but netted only about half the income, the logic of producing first-quality space was clear (Willis, 1995, p. 26-27).

Figure 1 depicts a typical workday scene in the Metropolitan Life Insurance Company Building, a structure dating back to 1896, located in New York. The image showcases an office unit featuring floor-to-ceiling windows on both sides, a spacious ceiling, a compact layout, effective daylight distribution, and a desk lamp at each workstation.

The presence of a lamp at each station enhances visual clarity during periods of reduced daylight, a traditional approach that was neglected for a considerable period but is highly valued in modern times, especially for green building rating system.

The integration of daylight and artificial lighting on workstations is a vital aspect of workplace design, aiming to create a balanced and comfortable environment that enhances both well-being and productivity.

IPRGCS AND MELANOPSIN

According to Brown (2020), light reaching the eyes drives non-visual responses in humans, such as the suppression of the secretion of melatonin, known as the sleep hormone, and the establishment of the circadian rhythm. Prior to the 21st century, it was often believed that the only photosensitive cells in the eye were rods and cones. However, a new class of photoreceptors called intrinsically photosensitive ganglion cells (ipRGCs) was found around the beginning of the 21st century. These cells are believed to not only regulate the circadian rhythm but also play a role in vision by distinguishing patterns and tracking overall brightness levels. Additionally, they seem to enable ambient light to affect cognitive processes like learning and memory. Various physiological reactions, including sleep, migraines, and seasonal affective disorder (SAD), have been connected to light. Recent research has found a correlation between these responses and the functioning of ipRGCs (Lok, 2011).

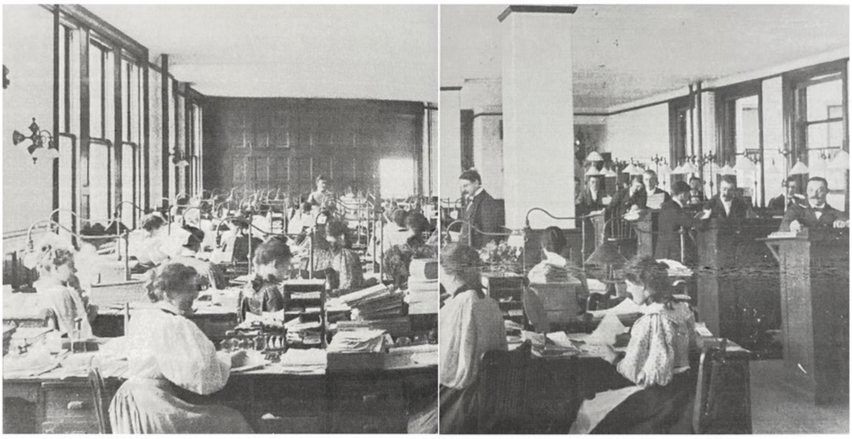

Figure 1: Workers in Metropolitan Life Insurance Company Building, New York (1896) (Willis, 1995, p. 30-31).

Retinal ganglion cells are photosensitive due to the presence of melanopsin, a photosensitive protein. ipRGCs combine intrinsic melanopsin-based phototransduction with extrinsic signals mediated by rods and cones. Phototransduction "is the transformation of light energy into biologically recognizable electrical signals, which takes place in the outer segment of cones and rods. The initial event consists of the absorption of light by visual pigments and the resulting changes in molecular conformations" (Oyamada, 2015, p. 68). Brown and Wald (as cited in Oyamada, 2015) state that rods, responsible for night vision, are sensitive to light, as they contain rhodopsin, which is capable of absorbing photons of around 500 nm, and cones, responsible for diurnal vision, which are specifically determined by the types of opsins present in its membrane: cones sensitive to blue, green and red.

Non-visual responses can be generated through a combination of any of five opsins, which are a group of light-sensitive proteins: melanopsin and rhodopsin, long-wavelength (or red), short waves (or blue), medium wavelengths (or green) (Brown, 2020). According to the researcher, ipRGCs are essential in the circadian phototransduction process, nonetheless, these cells are not the only photoreceptors involved. Zaidi et al. (2007) demonstrated that ipRGCs are functional in the absence of rods and cones.

Many functions of the human body are cyclical. The circadian rhythm controls not only the phases of sleep and awakening, but also heart rate, blood pressure, body temperature, performance, mood, and the production of hormones, such as melatonin and cortisol.

The greatest biochemical correlation of light-dark cycles is provided by the pineal melatonin rhythm. Under typical circumstances, melatonin is exclusively produced during the night, serving as the internal representation of the environmental photoperiod, specifically indicating the duration of the night. The light stimulus is taken from the photoreceptors, present in the retina, and transported directly to the suprachiasmatic nucleus (SCN), via the retinohypothalamic tract. The synthesis and period of melatonin production requires a signal from the SCN to the pineal gland, where melatonin production takes place. The melatonin rhythm is a marker of the circadian rhythm (Lockley; Arendt; Skene, 2007).

Given that a significant number of modern office buildings were not designed with considerations for daylight penetration or circadian rhythm alignment, and they often lack sufficient daylight in workspaces due to factors like glass façade tint, aperture size, roller shades, and the distance of workstations from the façade, employees may experience fatigue, and diminished performance during their work shifts. Adding to the fact that most workers do not have good daylight access in buildings, nor experience an outdoor walk during the day, they are prone to circadian disruption. As the variation and richness of daylight elicit circadian rhythm entrainment (Duffy & Wright, 2005), these people are going to have poor sleep quality and high stress level, impacting on their health and work performance.

A METRIC TO QUANTIFY THE BIOLOGICAL EFFECTS OF LIGHT

A system that weighted irradiance according to the effective in vivo spectral sensitivity of the five known human retinal opsin proteins (melanopsin, rhodopsin, S- M-, and L-cone opsin) was proposed by Lucas et al. (2014). This was an initial response to the lack of a suitable metric for quantifying ipRGC-dependent ocular light responses. This framework has now been formalized into an International Standard, which includes a system of metrology that is compliant with International System of Units (SI) for ipRGC-influenced responses to light, according to Commission Internationale de l'Eclairage (CIE) S026 (Brown et al., 2022).

Lucas et al. (2014) proposed the Equivalent Melanopic Lux (EML) model, whereas the Lighting Research Center established the Circadian Stimulus (CS) model. The International Commission on Illumination (CIE) has also suggested a measure that is based on the same biological paradigm as EML, but with a different scaling (Schlangen; Price, 2021). Mathematically, one unit of EML is equal to 0.91 units of Melanopic Daylight Equivalent D65. Both the CS and EML models are grounded in spectral power distribution rather than relying solely on visual intensity. It is important to note that both models consider the light entering the eye in the vertical plane. This represents a deviation from the conventional approach to lighting, which focuses on illuminating the area where a task is performed or the object that needs to be viewed (Soler, 2019).

The WELL Certification has drawn parameters to support circadian health by setting a minimum threshold for daytime light intensity. It mandates that compliance be demonstrated at a minimum of 75% of workstations. EML should be measured on the vertical plane facing forward, at a height of 1.2 meters (4 feet) above the finished floor to imitate the occupant's view. This illumination level may encompass daylight and is consistently available from 9:00 AM to 1:00 PM every day throughout the year.

The minimum requirement for envelope glazing is either 15% or 25% of the total floor space that is routinely inhabited. The windows must have a visible light transmittance (VLT) that exceeds 40%.

METHOD

The efficacy of EML was assessed in two distinct building typologies using a singular floor plan as a prototype. The floor plan was derived from a real-life office building. The models consist of three scenarios:

Scenario 1) A building (45m x 45m) with a central core (15m x 15m) and no shading on the façade.

Scenario 2) A building (41m x 25m) with a lateral core (21m x 9m) on the western façade without external shadings.

Scenario 3) A building (41m x 25m) with a lateral core (21m x 9m) on the western façade and a redesigned façade layout.

Table 1 presents model parameters. The materials employed consisted of white-painted walls and ceiling in the room, along with a dark-coloured floor.

The analyses were performed on the equinoxes and solstices at 9am and noon (that is the range indicated in WELL Certification) in São Paulo, which is situated at a latitude of 23°30', and Berlin, which is located at a latitude of 52°31'. The selection of these cities was based on their distinct climate circumstances to assess the buildings' EML and illuminance performance.

The glass considered for São Paulo models was a double IGU green Tvis 32% and for Berlin it was a double IGU blue green Tvis 53%. The glass difference is due to the climate of each city. The north angle is indicated in Figure 2.

The core position to do this assessment was established according to the research conducted by Pisani and Figueiredo (2011). Based on their data survey of buildings in São Paulo, Brazil from 1979 to 2010, the main types of contemporary office buildings can be categorized into two typologies. The first is a central core design, which accounts for 21% of the sampled buildings. The second typology is characterized by a core that is positioned against one side of the building. This type can be further divided into two subcategories: buildings with the core located inside the building geometry (43.5% of the sampled buildings) and buildings with the core located outside the building geometry (21% of the sampled buildings). The analytical grid does not consider the core zone, which comprises stairs, elevators, and toilets. The models were examined, considering daylight as the sole lighting source.

The calculations were done using ALFA (Adaptive Lighting for Alertness) tool, which works in conjunction with the software Rhinoceros. ALFA is a tool that allows the prediction and control of the non-visual effects of light in architectural design. The results of the simulations are presented in EML.

ALFA performs only static calculations, not climate based, and it has some limitations in terms of material variety. To enhance the realism of the simulations for each city, it was decided to use the recurrent skies of each location. For this experiment it was considered two types of skies: clear and hazy for both cities.

The proposed façade design (scenario 3) was derived from the concept of façade division as presented by Hausladen et al. (2004), where they define the function of every part of the façade. According to the authors, each area has a specific purpose, whether it be for distributing daylight, providing views of the outside, or allowing ventilation and thermal control. The proposed design (Figure 3) incorporates glasses with two distinct VLT and a light shelf between them to enhance the floor's performance in terms of both daylight reach and circadian potential.

	Values
Ceiling height	2.80m
Window size (with frame)	1.80m
Sill height	1.00m
Sky	Hazy and clear
Surrounding buildings	No
Grid spacing	1.00m
Number of view vectors per grid point	8
Horizontal grid (eye height)	1.20m
Ground spectrum Albedo	Uniform 0.15

Table 1: Model parameters.

Figure 2 shows both models without external shadings and Figure 3 shows the section of the proposed façade.

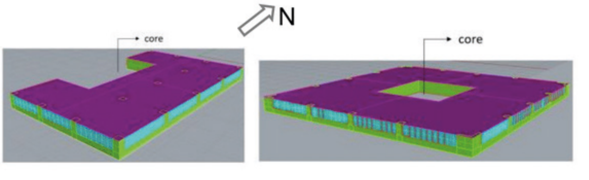

Figure 2: Lateral and central core model without external shadings.

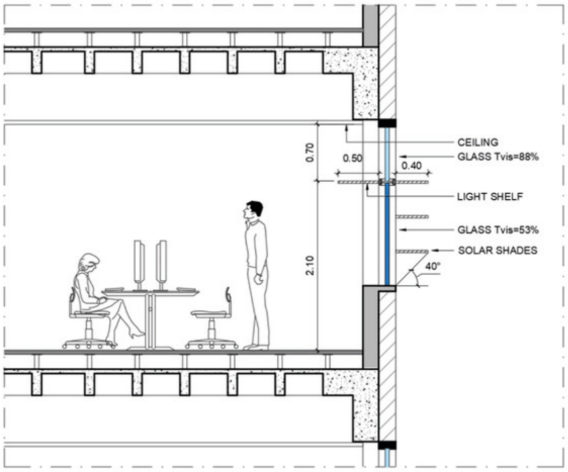

Figure 3: Proposed façade design – scenario 3 (Figueiredo, 2016).

This design proposal was specifically tailored for São Paulo. The light shelf was employed to enhance the spread of daylight across the floor. The glass positioned above the light shelf has a greater visible transmittance (Tvis) of 88% to enhance the amount of daylight entering the space and increasing interreflections. The glass under the light shelf exhibits enhanced thermal regulation because of the prevailing climatic conditions, however, because of the external solar shades, glass VLT can be higher compared to the standard solution. Solar shades were employed to obstruct direct sunlight, so preventing glare.

RESULTS AND DISCUSSION

The square building (scenario 1) and the rectangular building (scenario 2) typologies calculated for São Paulo complies with WELL certification in all scenarios (hazy and clear skies), during the calculated days. Figure 4 indicates the EML results for both typologies at 9am an noon during equinox and solstices, with the vertical plane facing forward. In the rectangular model, the area with the highest circadian potential is up to 9m from the longest façade. This area is best suited for placing workstations, mainly perpendicular to the façades. The areas with lower circadian potential could be used to place short-stay areas, e.g., circulation, archives, equipment, restrooms, and storerooms.

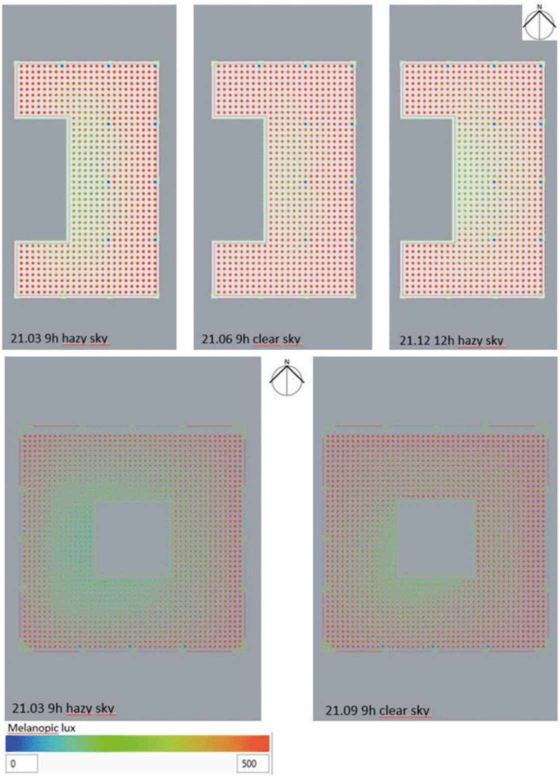

Figure 4: São Paulo model performance.

In the square typology (scenario 1), the area with the highest circadian potential is up to 15m from the eastern façade. As the building is symmetrical, the same distance would repeat in the opposite façade during the afternoon. The closer the core is to the facade, the better the performance in terms of the circadian rhythm. The glass selected for the model, commonly used in buildings in São Paulo, does not meet the VLT requirement for WELL Certification.

While the outcomes appear acceptable, the extreme brightness near the building's façade makes it necessary to close the blinds, so depriving users of the advantages of daylight and views outside.

In all circumstances, neither typology calculated for winter solstice for Berlin meets the requirements for WELL Certification, as shown in Figure 5. Daylight exhibits reduced efficacy throughout the winter season, despite the utilization of a high VLT glass. At times, during equinox and summer solstice, the amount of daylight near the windows would be excessive and internal blinds would have to be closed to avoid glare. The glass selected for Berlin model would meet the VLT requirement for WELL Certification.

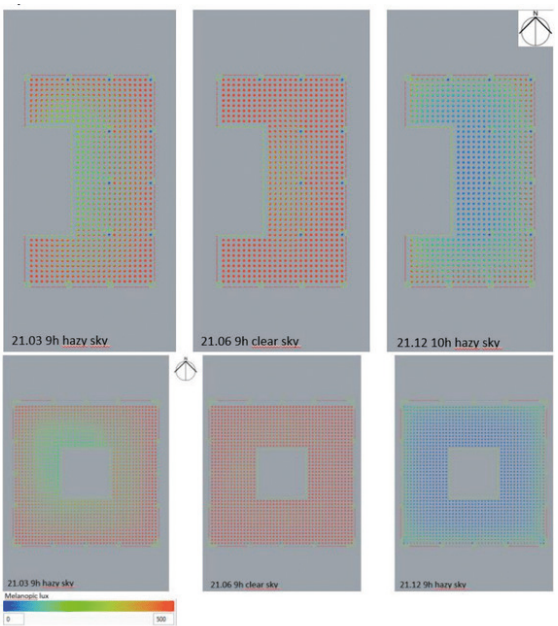

Figure 5: Berlin model performance.

Figure 6 displays the outcomes of the proposed façade design (scenario 3) in the rectangular model, alongside the outcomes of the standard facade (without solar shadings). The proposed façade design shows a decrease of 16,800lux in illuminance at the windows compared to the typical facade. This decrease may also suggest a lower likelihood of glare. Nabil and Mardaljevic (2005) determined the threshold for glare likelihood as 3,000 lux. On the other hand, near to the core (i.e. 16m from the shell) the reduction was 149 lux between solutions. The decrease in illuminance is more abrupt in the standard facade from the shell to the core compared to the proposed façade design. The controlled illuminance in scenario 3 provided by the external solar shadings and the solar control glass allows views outside. Another advantage of the proposed design is that, if necessary, a blind can be installed beneath the light shelf to mitigate eventual glare or privacy concerns while still allowing some daylight inside (above the light shelf). The calculation comparison indicates that the VLT glass combination and the light shelf improves daylight and circadian rhythm potential performance.

Both glasses selected for the model would meet the Tvis requirement for WELL Certification. The EML criteria would also be met considering the vertical plane facing the shell.

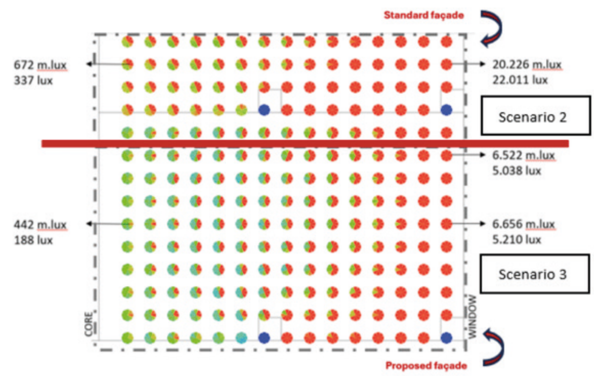

Figure 6: Scenario 2 and 3 performances with the proposed façade design.

Except for winter, this concept would provide advantages to buildings in Berlin throughout the year. An analysis of the necessity for exterior sun shading must be conducted.

CONCLUSIONS

The history of architecture has shown that certain traditional approaches could be considered today to enhance daylight performance and buildings occupants' life quality. Reducing the depth of buildings and aligning windows with the ceiling can enhance the distribution of daylight. The studies conducted in this work demonstrate that considering various façade solutions can optimize daylight distribution, reduce glare probability, and promote a healthier circadian rhythm to users.

LIMITATIONS AND PERSPECTIVES FOR FUTURE RESEARCH

Despite the advances presented in this study, some limitations must be acknowledged. Firstly, the simulations were conducted based on static scenarios and specific times of day (9 a.m. and 12 p.m.), which do not capture the full seasonal and climatic variability observed throughout the year in São Paulo an Berlin. The tool used (ALFA) does not perform dynamic simulations based on hourly climate data, which may limit the accuracy of the results in relation to the actual behaviour of natural light in the built environment.

Additionally, the adopted model did not consider the influence of furniture, internal partitions, the effective use of blinds throughout the day, variation in space occupancy, or possible changes in office layouts. Such factors can significantly impact the distribution of natural light and, consequently, the effectiveness of circadian stimulus.

Another relevant point concerns the representativeness of the facade materials and optical parameters adopted, which can vary considerably in the national market due to availability, costs, and regional construction practices. It is therefore recommended that future studies consider the diversity of facade solutions found in different climates.

Although the study aligns with international metrics, such as EML and WELL Certification, the Brazilian context still presents additional challenges, such as the low adoption of health and wellness certifications in commercial buildings, budgetary constraints, and cultural barriers to the implementation of new construction technologies.

Future research perspectives include conducting annual dynamic simulations using hourly climate data (based on TMY or local meteorological records), as well as post-occupancy studies that assess users' perceptions regarding visual comfort, productivity, and well-being.

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