OFFICE BUILDING TYPOLOGIES AND CIRCADIAN POTENTIAL

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ABSTRACT
Circadian rhythms are internal manifestations of the solar day that allow adaptations to environmental temporal changes. Mood disorders are often associated with disrupted circadian clock-controlled responses, while disruption of circadian rhythms is correlated with jet lag, night-shift work, or exposure to artificial light at night. Modern lifestyles patterns lead to a disruption in the circadian rhythm, resulting in several diseases. Circadian disruption is one of the factors raised, alongside smoking, diet, fatigue, and sleep quality, increased body mass index and obesity. The lack of enough daylight during the day and the exposure to electric light at night has disconnected people from the environment, eliciting psychological problems. The objective of this research is to analyze the circadian potential of three building models according to WELL Certification, compare their performance, and draw design guidelines about circadian rhythm and users' well-being for office buildings. Adaptive Lighting for Alertness (ALFA) tool was used to calculate the Equivalent Melanopic Lux for WELL Certification criteria in the scenarios. The results indicate that shallow office plans could benefit users, providing them with a regular circadian rhythm which improves sleep quality, reduces stress, and prevents serious diseases.

Key words: Daylighting, circadian rhythm, ALFA.

1. INTRODUCTION

Circadian rhythms are internal manifestations of the solar day that allow adaptations to environmental temporal changes. The exposure to light-dark (day-night) cycles suggests temporal information to the whole body via humoral and neural communication. There is strong evidence that associates circadian rhythms, mental health, and mood regulation. Mood disorders are often associated with disrupted circadian clock-controlled responses (sleep and cortisol secretion), while disruption of circadian rhythms is correlated with jet lag, night-shift work, or exposure to artificial light at night (WALKER *et al*., 2020).

Office workers spend most of their time indoors, which reduces the amount of daylight they experience over the years, and increases the exposure to electric light, especially in the evening. Light exposure is the main cause affecting circadian rhythms (KANTERMANN, 2013), particularly daylight (FIGUEIRO; NAGARE; PRICE, 2018). Modern lifestyles pattern leads to a disruption in their 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 and Littlefair (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.

Our living pattern has changed over the years due to artificial resources, technology, globalization and so forth. The invention of electric light brought many benefits, such as extending working hours beyond sunset. By the end of the 20th century technology increased the number of apparels we need daily. Concerning architecture and building design, daylight use has been forgotten by most architects due to electric lighting, mainly in the LED era, in which consumption and heat generated by the lighting sources are negligible.

Along with technological development, so did people's stress level. The lack of enough daylight during the day and the exposure to electric light at night has disconnected people from the environment, eliciting psychological problems. Stress causes may vary, however daylighting performance in buildings might be another factor to be considered when mental health and life quality are at risk.

According to Jung *et al*. (2010) the exposure to bright daylight higher than 10 000 lux can decrease cortisol level, which is the stress hormone, and the exposure to daylight for at least three hours a day can reduce work stress and dissatisfaction (ALIMOGLU; DONMEZ, 2005). Another example of how light affects us is drowsiness after lunch. Kaida *et al*. (2006) demonstrated in their research that half an hour's exposure to daylight between 1000lux and 4000lux was almost as effective as a short nap in reducing post-lunch drowsiness, normal in healthy individuals.

When daylight was the main resource for lighting interiors, office buildings were designed to make the most of it. The importance of daylight can be seen throughout the history of skyscrapers in Chicago and New York since the end of the 19th century. The quality and rentability of office space depended on large windows and high ceilings that allowed daylight to penetrate as deeply as possible. Therefore, office depth (the distance from the windows to the innermost wall or public corridor) was determined by daylight reach before the introduction of fluorescent bulbs in the 1940s. The building was designed inside out, from the smallest cell (the single office) to the full floor plan (WILLIS, 1995).

> The maximum of twenty to twenty-eight feet[1] 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[2] deep leased for $3.00 per square foot, while space twenty-five[3] feet brought only $2.60, and fifty feet[4], 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).

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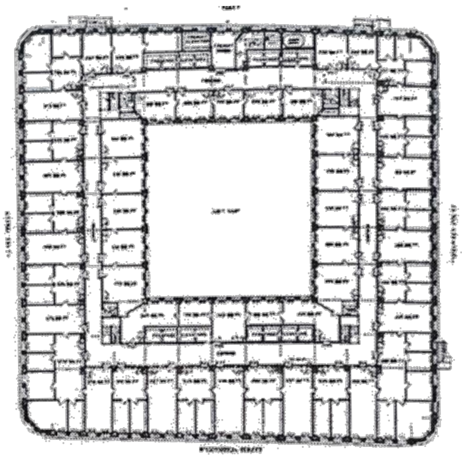
[1] Twenty feet equals 6.09m and twenty-eight feet equals 8.53m.

[2] Fifteen feet equals 4.57m.

[3] Twenty-five feet equals 7.62m.

[4] Fifty feet equals 15.24m.



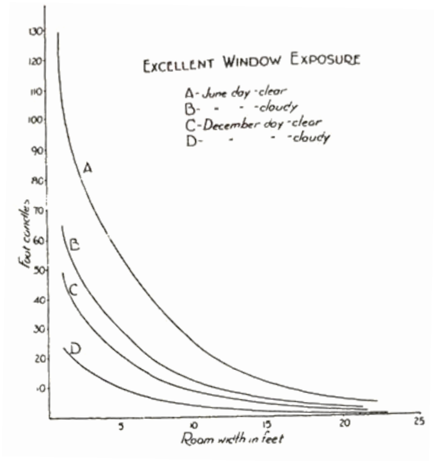


Figure 1 – Conway Building (1912), in Chicago (WILLIS, 1995, p. 62).

Figure 2 – Measurements of daylight illumination in office buildings, showing decrease in amount of light, according to distance from windows (WILLIS, 1995, p. 26).

Figure 1 indicates an example of a Chicago building from the beginning of the 20th century, which was the typical building: the hollow square type. In this case the plan had two rings of offices: perimeter and inner court. It provided good plan efficiency and well-lit offices. This plan survived into the twenties. Figure 2 displays the window exposure and daylight illumination measurements of that time, which reinforces how form follows finance, and draws guidelines to architectural design. There were variations in the position of the light court, such as an ‘L”, “H” or “U”. In Figure 3 it is possible to see the performance of the office unit during a workday in the Metropolitan Life Insurance Company Building, a building from 1896, in New York: windows reaching the ceiling on both sides of the office, high ceiling height, shallow room, good daylight distribution, and a lamp at each station. The lamp at each station improves visual acuity when daylight diminishes, an old strategy that was forgotten for a long time but is so appraised nowadays.

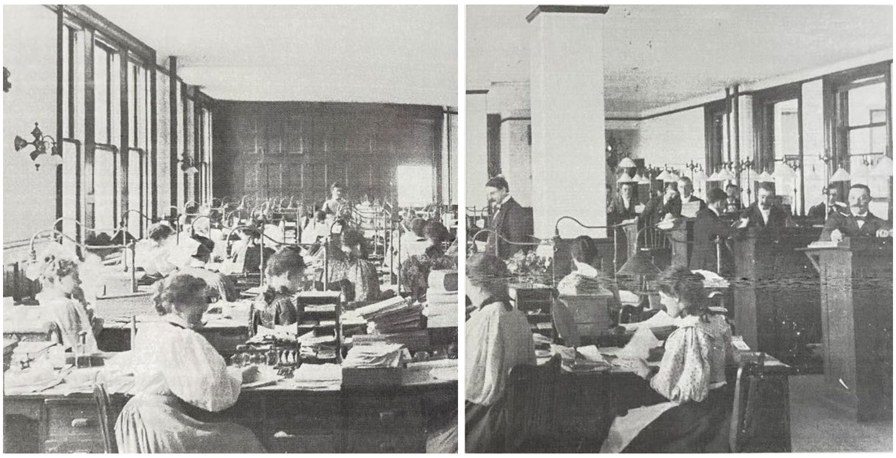


Figure 3 – Workers in Metropolitan Life Insurance Company Building, New York (1896) (WILLIS, 1995, p. 30, 31).

However, as civil engineering technologies developed, as well as lighting fixtures, bulbs and air conditioning, large spans were possible resulting in open office working areas. Although this type of office has allegedly demonstrated advantages in productivity, many occupants end up working far away from windows, decreasing their access to daylight and views to the exterior, which impacts on their circadian rhythm.

According to Skene *et al*. (1999), daily light–dark patterns incident on the retina reset the biological clock and entrain its timing to match the local 24-hour light–dark pattern. The light that reaches the eyes leads to non-visual responses in humans, such as the suppression of melatonin secretion, known as the sleep hormone, and the establishment of the circadian rhythm. The center that governs mammalian chronobiology is the suprachiasmatic nucleus (SCN) of the hypothalamus, which receives connections from the retina that informs the system about the existence of light. Melatonin is secreted by the pineal gland, obeying the SCN stimulus in the absence of light, translating the photic information into a chemical stimulus to all cells.

Exposure to light interacts with the SCN and can alter clock cycles. Intense light in the late afternoon slows down the clock, and intense light in the early morning sets the clock ahead (MARTINEZ; LENZ; MENNA-BARRETO, 2008). Pineal melatonin rhythm is the main marker of circadian rhythm (LOCKLEY; ARENDT; SKENE, 2007).

In 2002, Berson *et al*. identified a new class of photoreceptor known as intrinsically photosensitive retinal ganglion cells (ipRGCs), which are the primary ones involved in circadian phototransduction, that is the process used by the retina to convert light into electrical signals for the SCN (FIGUEIRO; NAGARE; PRICE, 2018). It is noteworthy that ipRGCs are the main cells to circadian phototransduction, however in According to the Rea *et al*. (2005), rods indirectly regulate the synthesis of the circadian phototransduction pathway's absolute threshold through the AII amacrine neuron, the brain region that regulates rod or cone signals to the ganglion cells.

The circadian rhythm is spectral sensitive, which means that according to the color temperature that falls on the retina and the amount of time of exposure, the body may experience either alertness or relaxation conditions. The ipRGCs communicate light exposure to the brain and is known to be shifted to the blue wavelength portion of the spectrum (peak around 460 nm, as indicated in Figure 4) concerning the photopic sensitivity curve (Figure 5), hence the spectral character of daylight also becomes a sensitive factor in the magnitude of the predicted non-visual effect (MARDALJEVIC *et al*., 2013). The blue-light sensitive photopigment is called melanopsin and is located in the ipRGCs (REA et at., 2005).

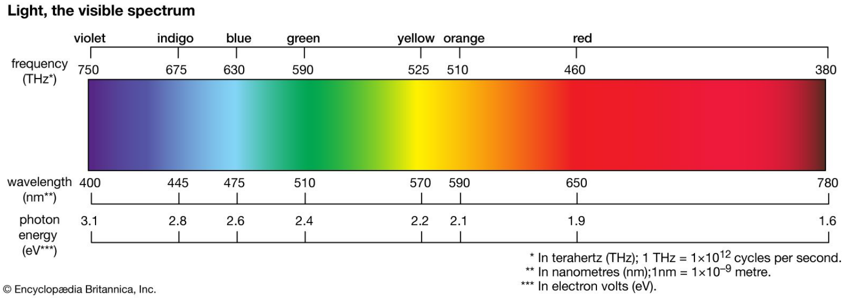


Figure 4 – Visible spectrum of light (ENCYCLOPÆDIA BRITANNICA, 2023, s/p).

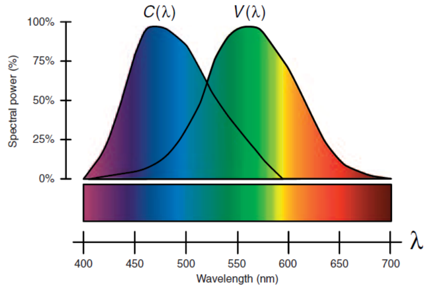


Figure 5 – Spectral response of the visual system (photopic curve V(λ)) and the circadian system (melanopsin action spectrum C(λ)) (ANDERSEN; MARDALJEVIC; LOCKLEY, 2012, p. 40).

It was measured that the acute melatonin suppression (circadian system sensitivity) occurs with polychromatic light which peaks in blue wavelength (color temperature of 4000K and above), eliciting alertness (FIGUEIRO; NAGARE; PRICE, 2018). However, it is not only color temperatures with blue spectrum peaks that suppress melatonin production. Lewy *et al*. (1980 apud FIGUEIRO; NAGARE; PRICE, 2018) demonstrated that a two-hour exposure to 2500 lux at the cornea level from an incandescent light source at night significantly suppressed melatonin production in healthy subjects. Incandescent light sources have a color temperature of 2700K, which means that it is red enriched instead of blue, common in light sources with color temperature of 4000K and higher.

It is significant that lighting levels concerning circadian rhythm are at eye level, not at desk level (0,75 m above finished floor), as standards usually present, which adds a different metric to office design.

Table 1 indicates the research results of Aoki *et al*. (1998 apud FIGUEIRO; NAGARE; PRICE, 2018) about the amount of time and the illuminance required to suppress melatonin with a color temperature of cool-light fluorescent (estimated to be ranging from 4000K to 5000K, based on manufacturers' terminology). The higher the illuminance, the shorter exposure duration to suppress melatonin is needed. Based on this research, it is possible to infer that daylight has a stronger effect on the alertness matter with the advantage of color change and intensity during the day, which informs the time of the day to our body.

According to Andersen, Mardaljevic and Lockley (2012), several non-visual effects were identified based on day subdivision. From 6 to 10am sufficient daylight illuminance can serve to phase advance the clock in the majority of people (circadian resetting); from 10am to 6pm high levels of daylight illuminance may lead to increased levels of subjective alertness without exerting substantial phase shifting effects on the clock (alerting effects of daylight); from 6pm to 6am light exposure that might trigger the non-visual effect is to be avoided so as not to disrupt the natural wake-sleep cycle (bright light avoidance).

Table 1 Melatonin suppression based on exposure duration and illuminance (based on Aoki *et al*. 1998 apud FIGUEIRO; NAGARE; PRICE, 2018).

Exposure duration (min)	Illuminance to suppress melatonin (lux)
30	393
60	366
90	339
120	285

Considering that most contemporary offices buildings[5] were not designed based on daylight reach, nor circadian rhythm entrainment, and they provide insufficient daylight in working areas due to glass façade tint[6], aperture size, roller shades, and working station distance to the façade, workers can experience drowsiness, fatigue, and poor performance during their work shift. Extended working hours and office lighting can contribute to melatonin suppression due to light intensity (at least 500lux in the working area) and spectrum (4000K). 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. According to Walker *et al*. (2020) it's been long recognized that exposure to light at night can disrupt biological and behavioral rhythms, leading to negative consequences for health.

Recent metrics have provided parameters to evaluate the circadian stimulus of an area. They are the M/P ratio and the Equivalent Melanopic Lux (EML). The M/P ratio (melanopic/photopic), according to Miller and Irvin (2019), is a new spectral metric that has been used to assess the consequences of light related to health, well-being and states of alertness, relaxation, or sleep. Photopic vision is the designation given to the sensitivity of the eye under conditions of light intensity that allows the distinction of colors (FOSTER, 2020). Melanopic illuminance defines the magnitude of human circadian light responses consistently providing the best available predictor for responses of the human circadian system (BROWN, 2020). This relationship M/P compares the melanopic potential (referring to ipRGCs) with the ability of the light source to produce light appropriate for the vision of details during daytime (photopic) (MILLER; IRVIN (2019). Research shows that the more energy is emitted in the spectral range to which ipRGCs are most sensitive (460 nm to 480 nm), the greater is the light source's alertness potential (TICLEANU; LITTLEFAIR, 2020); on the other hand, the lower the M/P ratio, the better the conditions for sleep and relaxation.

For different light source Spectral Power Distributions (SPD), the melanopic spectral efficiency function can be used to determine melanopic illuminance (given in units of Equivalent Melanopic Lux (EML)). It indicates the absorption of light by means of melanopsin, the photosensitive protein present in the ipRGCs receptors. The WELL Certification proposed thresholds to analyze an area and verify whether it has an acceptable performance to comply with the requirements. Hourly EML results within the time period 7:00-10:00 am are evaluated to determine all vectors that achieve the minimum stimulus requirement (250 EML) for all three analysis hours. Such vectors are then defined as Circadian-Effective (CE) for that day (KONIS, 2017). The vectors are the head and sight direction.

2. OBJECTIVE

The objective of this research is to analyze the circadian potential of three building models according to WELL Certification, compare their performance, and draw design guidelines about circadian rhythm and users' well-being for office buildings in São Paulo, Brazil.

3. METHOD

The method was divided into 2 steps, as follows:

1. Model and assumptions.
2. Simulation workflow.

To particularly address non-visual effects of light during design, it is crucial for designers to have access to design support tools and performance criteria built on the basis of accessible knowledge. These instruments can assist designers in evaluating, comprehending, and enhancing the circadian efficacy of

[5] In São Paulo.

[6] Façade tint varies according to thermal comfort and, hence, air conditioning consumption.

various daylighting systems. WELL Certification was chosen due to its straightforward parameters to analyze building's performance over office users' circadian rhythm.

One of the assessed typologies was the hollow square building type, very common during the end of the 19th century and beginning of the 20th in Chicago and New York[7], when electrical resources were neither available nor efficient, and designers had to make the most of daylighting. The Conway Building was selected because it was designed considering daylight performance, which was a very important issue when it was built. The building has gone through several renovations over the decades, and it is still operating nowadays. The façade, nonetheless, remains the same. It should be noted that the typology performance is relevant for this research, not the Conway Building's performance itself. Its plan was used as a model to understand the performance of this typology (hollow type), and it was calculated for São Paulo. It was, therefore, named Model 1. Two other models were created based on Model 1's plan dimensions, but with a variation in core position, which was important to understand performance and compare architectural solutions. The modification on the core position was based on Pisani and Figueiredo (2011) office building typology research, as it is explained in item 3.1, model, and assumptions. Although Conway Building size is not usual in São Paulo, it was chosen to establish daylight reach and circadian rhythm potential guidelines.

3.1. Models and assumptions

One floor plan with no shade based on a real office building was modeled to compare EML in three scenarios: 1) Hollow square type building (Model 1, Figure 6) 2) Same dimensions as Model 1, but the core changed to the central of the building(Model 2, Figure 7) 3) Same dimensions as Model 1, but the core changed to the borders of the building (Model 3, Figure 8). The 3D model and the building properties are presented in Table 2 and 3. The analyses were performed for March 21st at 9am, in São Paulo (23°30' latitude). Model 1 was calculated as the 11th floor, considering the baseline design building with 22 floors.

The core position to perform this study was determined based on Pisani and Figueiredo (2011) research. According to their data survey involving buildings from 1979 to 2010, from São Paulo, Brazil, the main contemporary office buildings typologies have either a central core (Model 2) (21% of the sampling) or a core that leans against one side of the building (Model 3) (inside building geometry (43,5% of the sampling) or outside building geometry (21% of the sampling). The core zone includes stairs, elevators, and bathrooms which are not considered in the analysis grid. The models were analyzed considering daylight as the only source of lighting.

It was chosen to maintain the first model shape to evaluate how the core position would affect EML and circadian efficiency, although the recurrency of the square plan is low in the selected city. Several conditionings determine buildings' shapes and core position, e.g.: land shape and dimensions; alignment with the main road; immediate surroundings; urban legislation and zoning; building standards and legislation; daylight use; external views; size indicated by the real estate market for the office floor plate; construction potential and relationship between ceiling height and costs per square meter; green building certification, among others. Evaluating three different plan shapes would lead to possible impairments to compare daylight and circadian performances. Therefore, the authors decided to maintain the same plan shape and change core position in order to compare buildings' EML.

Table 2 Building properties.

Property	Value
Window to wall ratio	66%
Climate	São Paulo
Floor plan length	60x55 m
Ceiling height	2.80 m
Window size (without frame)	1.90 m x 1.65 m
Sill height	0.90 m
Surrounding buildings	No

Table 3 Model properties.

Property	Specularity	R (P)	R(M)	M/P
Wall	0.4	81.2%	76.8%	0.95
Floor	0.2	23%	21.9	0.95
Ceiling	0.4	82.2%	77.4%	0.94
Glazing	Tvis: 32%			1.09
Analysis grid spacing	1.00 m			
Number of view vectors per grid point	1			
Horizontal grid (eye height)	1.2 m			
Sky condition:	clear			

Table 2 indicates building properties and Table 3 indicates model properties. ALFA library brings materials finishes with indications of Reflectance Photopic R(P), Reflectance Melanopic R(M), and

[7] Chicago and New York are two cities where high-rises history developed. For the first half of the twentieth century, New York and Chicago constituted USA's only skyscraper metropolises (WILLIS, 1995).

Melanopic/Photopic ratio. The Tvis (glazing) chosen is the closest to the Tvis of office buildings recently built in the city of São Paulo. The ceiling height was defined based on São Paulo's triple A office buildings. The ceiling height of the original building is lower than Triple A buildings, according to recent pictures of Conway Building.

It was considered only one view vector, which simulates the person's head and eye position. All vectors are facing the computer. The proposed models' layouts aim to minimize glare from the façade. Model 3 had the desks shifted (facing windows) to improve the performance from the circadian point of view, otherwise it would have a much inferior performance. Desks positions were assigned to occupy the office area, to understand plans' circadian performance, rather than be a feasible occupancy solution.

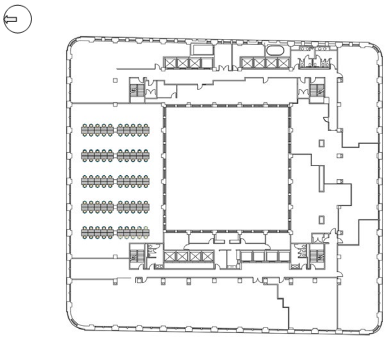


Figure 6 – Model 1.

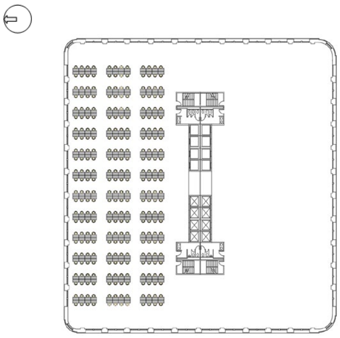


Figure 7 – Model 2.

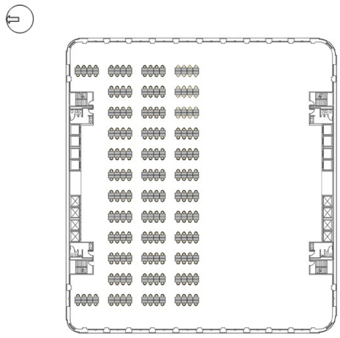


Figure 8 – Model 3.

3.2. Simulation workflow

In order to represent the occupant's eye-height, a vertical measurement grid was positioned 1.2 m above the floor, with spacing compatible with the computer arrangement. Material properties to all surfaces and grid dimensions were assigned to ALFA (Adaptive Lighting for Alertness), a tool developed by Solemma[8] and installed inside Rhinoceros. The sensors were distributed according to the considered layout, with only one view direction: the computer screen or facing forward, as WELL Certification requires. The 3D office space was modeled in SketchUp and imported into Rhinoceros in which orientation was assigned. The calculation was done based on the location selected from the list (São Paulo), for 21st March at 9am.

ALFA is a tool that allows the prediction and control of the non-visual effects of light in architectural design, to create safer, healthier, and more productive environments (SOLEMMA, 2021). It can estimate the amount of natural and/or artificial light absorbed by the non-visual photoreceptors of the occupants of the building, given their location and the direction of vision. The results of the simulations are presented in two ways: state of alert (M/P ratio) and EML.

ALFA indicates these parameters through M/P>0.9, which elicits alertness, M/P<0.35 stimulates state of relaxation, and M/P<0.9 is indicated as "neither". Konis (2017) points out that some areas in buildings can be named biologically dark areas, which means they are not circadian-effective, which can be understood as the areas indicated as "neither" by ALFA.

In addition to the simulation in the vertical plane, the software develops simulations in the horizontal plane (0.76m from the floor), so that it is possible to understand the lighting context of the simulation. The material library available in the program has some limitations in terms of variety, but the M/P ratio exhibited for all materials indicates that materials selection should also be observed in architectural design.

The assessment in this research used WELL Certification to evaluate architectural design circadian potential. According to the certification, EML should be 200 equivalent melanopic lux (eq.m.lux) at 75% or more of workstations. This light level may incorporate daylight and is present for at least the hours between 9:00 am and 1:00 pm for every day of the year. All evaluations in this research disregarded electric lighting. The certification evaluates people's adequate exposure to daylight and views, which they call "right to light" (INTERNATIONAL WELL BUILDING INSTITUTE, 2023). M/P ratio was not analyzed in this work.

Concerning right to light credit, lease depth and window access should be met in this requirement as follows: a) 75% of the area of all regularly occupied spaces should be within 7.5 m of view windows; b) 75% of all workstations should be within 7.5 m of an atrium or a window with views to the exterior; c) 95% of all workstations should be within 12.5 m of an atrium or a window with views to the exterior.

[8] Solemma is an international group of designers, building scientists, educators and environmental performance consultants dedicated to crafting tools using cutting edge, research-validated methods.

4. RESULTS

It should be noted that the certification requires at least 4 hours per day for every day of the year. As this study represents part of a major research, it will present only one specific hour on one specific day, and one specific sky condition. Nevertheless, it is challenging to state that these exact results would occur under distinct sky conditions and periods of the year. This study, however, still provides an indication of how buildings would perform in terms of circadian stimulus. ALFA presents results for a specific day and time of the year, instead of annual daylighting calculations. Although it is restrictive it still indicates design parameters.

The Model 1 (building with an atrium – 110 views) ALFA calculation indicates that it meets the WELL Certification requirements (Figure 9). Complying to WELL Certification criteria, 75% of the area of all regularly occupied spaces is within 7.5 m of view windows, 90% of views (vectors) are above 250 eq.m.lux (disregarding electric light) and 95% of all workstations are within 12.5 m of an atrium or a window with views to the exterior. The distance from the exterior wall to the inner window (atrium) is 17 m. The average work plane illuminance is 317lux and 40% of the sensors are above 300lux. This result indicates that the calculated floor plan meets WELL requirements for the day and time considered. This model shows advantages because even in the yellow circled point, which has the lowest work plane illuminance (204 lux), it has a sufficient EML (347 eq.m.lux). This point is 9.50m away from the external façade and 8m from the inner façade, promoting views to the exterior.

Model 2 (288 views – Figure 10) indicates that 71.5% of the views (205 vectors) are above 250 eq.m.lux. The average work plane illuminance is 337lux and 41.7% of the sensors are above 300lux. It does not meet WELL Certification EML criteria, although it was very close. The distance from the exterior wall to the core is 21.90 m. Figure 8 indicates yellow rectangles, where vectors are 250 eq.m.lux and above, and purple rectangles where vectors have insufficient EML. Desks turned to windows until 23.70 m from the east façade and 16.60 m from the north facade, meet required EML to WELL Certification on March 21st at 9am. More studies should be considered for other times of the day and days of the year to present a complete evaluation of the full floor plan for the certification matter.

Model 3 (304 views – Figure 11) indicates that 34.9% of the views (106 vectors) are above 250 eq.m.lux. It does not meet WELL Certification criteria. The average work plane illuminance is 135lux and 16.1% of the sensors are above 300lux. Only half of the floor plan was calculated, like Model 2. It is possible to notice that in this scenario there are fewer vectors with a minimum of 250 eq.m.lux (yellow rectangles). The purple rectangles indicate that those vectors do not have sufficient eq.m.lux. This typology has the higher recurrency among buildings in São Paulo and it had the poorest performance. Core position diminishes the number of windows, limiting buildings' circadian potential.

The research indicates that buildings with an inner court would provide a healthier environment, with a higher amount of EML. The fact that contemporary typologies no longer have a central atrium for the entry of daylight means that the use of the central area of the plant is impaired in relation to the performance for the circadian rhythm, according to the results analyzed. These results point to the maximum acceptable distance with typologies and openings. Whether the inner court is not viable, it is important to maintain rather short distances from workstations to windows and clear sight. It is noteworthy that these distances are valid to a 2.80 m ceiling height, a 32% Tvis glass, white ceiling, and white walls.

Table 4 summarizes models' performance, and it indicates that Model 1, the plan with an atrium, is the only one that meets WELL criteria. The shallow plan has a balanced daylight performance and a balanced EML, which leads to healthier occupants due to circadian stimuli.

Although office buildings with an atrium are rare nowadays, it brings an interesting perspective for architects in terms of occupant's well-being, and it stresses how the right amount of daylight enables an entrained circadian rhythm for workers.

The number of floors around the atrium could result in a less favorable daylight performance in the lower floors due to buildings height. However, the architectural design could consider different solutions for different floor demands in order to provide a better daylight quality for occupants.

Table 4 Models' performance.

	Longest window distance (m) with 250 EML or higher	% views above 250 eq.m.lux	% sensors above 300 lux	WELL certification criteria met
Model 1	9.5	90	40	✓
Model 2	23.7	71.5	41.7	X
Model 3	19.5	34.9	16.1	X

Figure 9 – Model 1. Melanopic Lux performance at 9 am, March 21st. The yellow circle indicates the lowest illuminance.

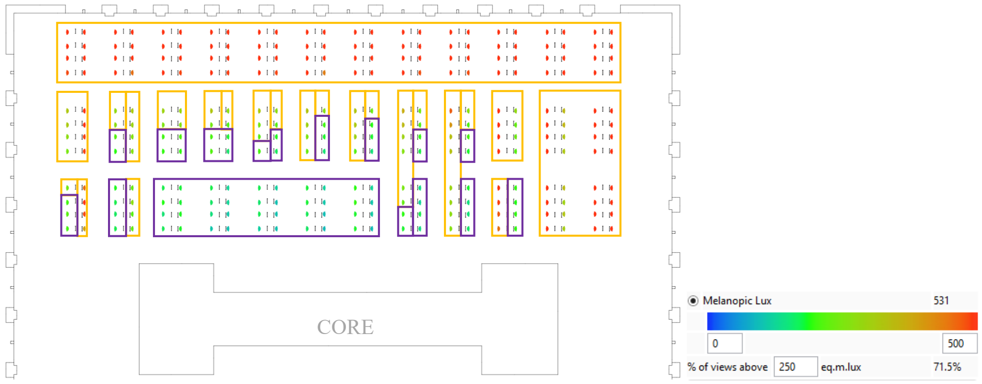


Figure 10 – Model 2. Melanopic Lux performance at 9 am, March 21st. The yellow rectangles indicate a minimum of 250 eq.m.lux and the purple rectangles indicate insufficient eq.m.lux.

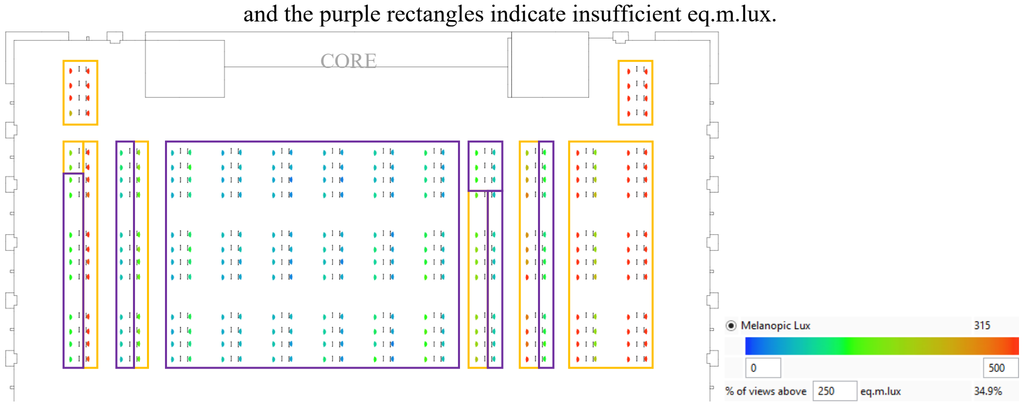


Figure 11 – Model 3. Melanopic Lux performance at 9 am, March 21st. The yellow rectangles indicate a minimum of 250 eq.m.lux and the purple rectangles indicate insufficient eq.m.lux.

5. CONCLUSIONS

This research examined the EML in three office building models and workspace performance, to draw design guidelines about circadian potential performance. One of the chosen typologies' dates from the beginning of the 20th century (Model 1), when daylight was an important asset for profitable leasing enable. As electric lighting promoted freedom for architects to design interiors disconnected from the surroundings, daylight became less important in the design. The advent of research on circadian rhythm and the discovery of ipRGCs brought to light the importance of vernacular choices in architectural design.

The other two models were selected based on a research that shows the highest recurrence of core position among office buildings that were built from 1979 to 2010, in São Paulo, Brazil. Model 1 with the inner court had a better EML performance due to its shallow plan and the atrium itself. Model 2 had a high performance, although it did not meet WELL Certification requirements. Model 3, the most recurrent typology among São Paulo's office building, had an inferior EML performance due to core position. Occupants would benefit from buildings with inner court and shallow plans, concerning their health and circadian rhythm.

Since people spend most of their lives working indoors and there has been proven the impact of the lack of daylight on occupants' health and circadian rhythm, the pursuit of this theme is relevant. It indicates that a proper design could benefit users, providing them with a regular circadian rhythm which improves sleep quality, reduces stress, and prevents serious diseases.

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