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APPROACH TO THE CIRCADIAN RHYTHM IN THE DESIGN OF DAYLIGHTING IN OFFICE BUILDINGS

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Abstract: The relevance of daylight went beyond issues of energy savings or illuminance required by standards, after the discovery of the third class of photoreceptors: intrinsically photosensitive ganglion cells (ipRGCs). These cells are responsible for non-visual responses, regulating the circadian rhythm, culminating, consequently, in the physiological and behavioral performance of individuals. This research aimed to analyze an example of the recurrent typology of office buildings in São Paulo, from the point of view of the performance of the users' circadian rhythm, with the objective of tracing design guidelines that aimed at taking advantage of natural lighting and well-being. being of its occupants. The method used the ALFA (Adaptive Lighting for Alertness) tool in the selected typology, in order to evaluate its potential in relation to the users' circadian rhythm. The results indicated the need to evaluate the pertinence of glass skin buildings for the city of São Paulo, whose window-to-wall ratio parameter exceeds that recommended by researchers in the area, as well as studies of facades based on the geometry of insolation, such as the analysis of the sky view factor and solar protection, in addition to the choice of selective glasses. So that users of office buildings can benefit from natural lighting, and the strategy becomes a viable resource, it is essential that architects design envelopes and internal spaces according to the reach of natural light, in quantities that favor the well-being, productivity and engagement of its occupants, and prevent the occurrence of glare.

Keywords: Circadian rhythm. Natural lighting. ALFA.

INTRODUCTION

The relevance of the application of daylighting in architectural design has become prominent as the number of researches on circadian rhythm increases, as well as the understanding that natural light does not only have the function of illuminating. Environments designed to make effective use of natural light can have profound impacts on users' health and well-being as their circadian rhythms become regular.

However, the reality of most buildings made of glass does not match the architects' justification for using this type of façade: visual access to the outside and natural lighting. According to Mardaljevic, Heschong and Lee (2009), the most common scenario in buildings with glass skins is that of lowered blinds and lights on – as a matter of convenience – these blinds can remain down for days, months or even years (REA, 1984). The occurrence of this scenario is due to the visual discomfort resulting from the high illuminance near the openings, even in buildings with solar control glazing.

According to Brown (2020), 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.

Until the end of the 20th century, it was believed that only the cones and rods were the photosensitive cells of the eye; however, at the beginning of the 21st century, a third class of photoreceptors was discovered: the intrinsically photosensitive ganglion cells[1] (ipRGCs). It is estimated that these cells, in addition to being responsible for synchronizing the circadian rhythm, may also play a role in vision – distinguishing patterns and tracking overall brightness levels – and seem to allow ambient light to influence cognitive processes such as learning. and memory. Many physiological responses have been associated with light such as sleep, migraine and seasonal affective

1 *Intrinsically photosensitive retinal ganglion cells*

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disorder[2] (SAD), and these have recently been associated with the activity of ipRGCs (LOK, 2011). Figure 1 indicates a magnification of the retina and photoreceptors.

Ganglion cells are photosensitive due to the presence of melanopsin, a photosensitive protein. The ipRGCs combine intrinsic, melanopsin-based phototransduction with extrinsic signals mediated by cones and rods. 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 the visual pigments and the resulting changes in molecular conformations" (OYAMADA, 2015, p. 68). Brown and Wald (1964), apud Oyamada (2015), state that rods, responsible for night vision, are sensitive to light, as they contain rhodopsin, which is capable of absorbing photons of about 500 nm, and cones – responsible by daytime vision – which are determined specifically by the types of opsin present in its membrane: cones sensitive to blue (460 nm), green (530 nm) and red (655 nm). Figure 2 – below – indicates the visible spectrum of light and the respective wavelengths.

Non-visual responses can be elicited through a combination of any of the five opsins, which is a group of light-sensitive proteins: melanopsin, rhodopsin, long-wavelength (or red)-sensitive cone opsins, long-wavelength (or red) short (or blue) wavelengths, medium (or green) wavelengths (BROWN, 2020). According to the researcher, the ipRGCs are primordial in the circadian phototransduction process, however, these cells are not the only photoreceptors involved.

However, Zaidi et al. (2007) demonstrated that ipRGCs are functional in the absence of cones and rods. The research evaluated blind individuals and found that circadian responses – neuroendocrine and neurobehavioral to light, and even visual awareness of light – are retained in visually blind individuals without a functional outer retina, confirming the discovery of a new photoreceptor system in the mammalian eye. These findings question the traditional view that rod- and cone-based photoreception mediates all visual responses to light (such as pupillary constriction and visual awareness) and suggest that these and non-visual circadian and neuroendocrine responses to light are driven primarily by a non-rod, non-cone, short-wavelength-sensitive photoreceptor system located in the ganglion cell layer.

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

The greatest biochemical correlation of light-dark cycles is provided by the pineal melatonin rhythm. Under normal conditions, melatonin is produced only at night, and it provides an internal representation of the environmental photoperiod, specifically the length 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 timing 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).

The circadian rhythm fluctuates on a 24.2 hour average in the absence of external time indicators. The daily patterns of light-dark (day and night) incident on the retina

2 *Seasonal Affective Disorder*

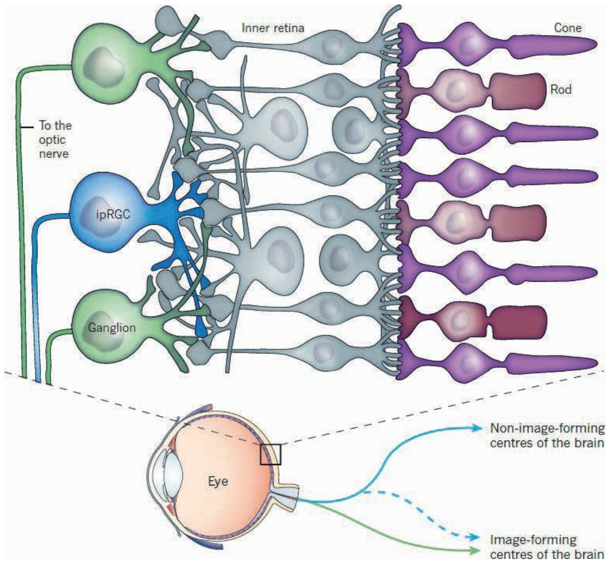

Figure 1 – Magnification of the retina and indication of photoreceptors

Source: LOK, 2011, p. 285

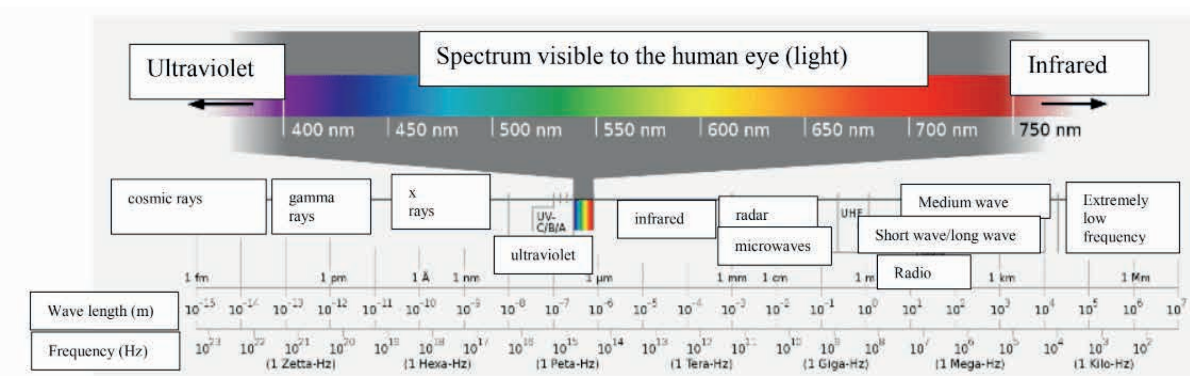

Figure 2: Visible Spectrum of Light

Source: FRANK, 2005, s/p

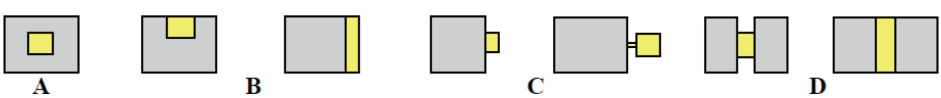

Figure 3: Classification of recurrent typologies in office buildings

Source: PISANI; FIGUEIREDO, 2011, p. 4

set the biological clock, adjusting its timing to correspond with the 24-hour pattern of local light-dark. Disturbances in this rhythm can cause diseases, such as poor sleep and performance, as well as increase the risk of more serious diseases, such as obesity, diabetes, among others. Published research on the non-visual effects of light and circadian rhythm, which compares artificial and natural lighting since the 1990s, indicates that lighting has a stimulating effect on people, with natural light being the most effective (FIGUEIRO; NAGARE; PRICE, 2018)

According to Foster (2020), if an individual does not receive enough light and if their circadian rhythm is not aligned with light-dark patterns, there are delays in the biological clock, and this individual may suffer from *Sleep and Circadian Rhythm Disruption*[3], which results in consequences – in the short and long term – and, if the individual has a vulnerability to mental illness, these symptoms can be exacerbated. Foster (2020) points out that the short-term consequences are: microsleep, irritability, concentration problems, lack of motivation, memory impairment, among others. Some long-term consequences are: physiological and psychosocial stress, cardiovascular disease, increased use of stimulants and sedatives, and metabolic syndrome.

Aoki et al. (1998) sought to identify the minimum light intensity capable of suppressing nocturnal melatonin levels measured in human saliva. Five healthy male volunteers were exposed to light at different intensities (<10, 500, 1000, 2500 and 5000lux). The light used in the experiment was a cool white fluorescent lamp. According to the nomenclature of lamps from the manufacturer Osram, this nomenclature (cool white) indicates a shade of 4000K. Melatonin suppression was found to be dependent on light intensity and duration of light exposure. The minimum intensities of light-suppressing nocturnal melatonin levels were calculated as 393, 366, 339, and 285lux for exposure durations of 30, 60, 90, and 120 minutes, respectively. These results suggest that less light intensity is sufficient to suppress melatonin in humans.

In two laboratory studies, conducted by Rea and Figueiró (2013 apud FIGUEIRO; NAGARO; PRICE, 2018), 28 subjects received (through LED light glasses) warm white light (color temperature 2760 K) for one hour. The first study exposed subjects to illuminances directly on the cornea of 8, 22 and 60lux, and the second study exposed subjects to illuminances directly on the cornea of 60, 200 and 720lux. The authors collected plasma melatonin samples before and immediately after exposure to light lasting one hour. While results from the first study did not show significant melatonin suppression from any of the lighting conditions, results from the second study showed significant post-exposure melatonin suppression from the 200 and 720lux conditions compared to dimmed lighting. Using a similar protocol, a third study was performed using a cool white light source (color temperature 6400 K). In these studies, subjects were exposed to one hour of illuminances of 115, 300 and 720lux directly on the cornea. The result of the research indicated that a higher illuminance of hot light (60, 200 and 720lux) is necessary, compared to cold light (6400K), to generate a reduction in the amount of melatonin close (between 15 and 20% approximately) (FIGUEIRO; NAGARE; PRICE, 2018). Although the ipRGCs have the peak of the sensitivity curve in the blue spectrum (450 to 480nm), warm light sources (2700K), with illuminances from 200 lux, can generate melatonin suppression.

According to Foster (2020), the amount of light that ipRGCs need (for a healthy circadian rhythm) is not a simple and straightforward

3 Sleep Disorders and Circadian Rhythm.

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answer. Critical factors for the regulation of intrinsically photosensitive ganglion cells to mediate light responses depend on intensity, duration of light stimulus, light color (wavelength), time of day (when the individual had access to light) and age (older people). young people demonstrate greater sensitivity to regulation of the biological clock due to exposure to light).

The author points out that – although most publications on the sensitivity of ipRGCs state their sensitivity to a wavelength of 480nm – there are researches which show melatonin suppression during exposure to 420nm wavelengths in primates. Foster says that – so far – the interaction of cones, rods and ipRGCs is unclear.

Figueiro et al. (2017) demonstrated that the time of day an individual receives natural light affects their circadian rhythm. The authors state that being exposed to light during the right period favors a regular circadian rhythm and point out that individuals, with greater exposure to natural light (from 8 am to 12 am), sleep better at night, report less depression and less interruption during sleep.

According to Andersen, Mardaljevic and Lockley (2012), natural light generally provides significantly higher illuminances than the design values, necessary according to the visual activity of the environments; however, the occurrence of high illuminances only happens near the openings. If typical illuminances in these zones are high – but not glare or the use of blinds – users who regularly occupy these well-lit spaces may perhaps experience regular circadian rhythms compared to those users positioned far from windows, who are habitually exposed to lower levels. lighting at eye level.

These surveys culminated in the demand for performance indicators for environments; consequently, the users. Recently, new metrics for calculating daylight, based on climate, have emerged, bringing promising guidelines for design (ANDERSEN; MARDALJEVIC; LOCKLEY, 2012). Understanding the effects of natural and artificial light on well-being indicate new paths for building design.

The objective of the research is to analyze the most recurrent typology in office buildings in São Paulo, according to the circadian rhythm of the occupants, considering two different scenarios: only natural lighting and only artificial lighting, with the aim of tracing design guidelines that aim at well-being. being, health and productivity of users.

MATERIALS AND METHODS

1. Selection of the recurrent typology of office buildings in São Paulo.
2. Modeling of the standard floor of the selected building and insertion of the ALFA tool parameters.
3. Simulation of the circadian performance of the standard floor of the WTorre building – Building 2 in the ALFA tool.

1 Selection of the recurrent typology of office buildings in São Paulo

In normal times – in the absence of a pandemic – part of the working population works at least 8 hours a day in office buildings. This demonstrates the need for research in the field of lighting, demonstrating how the visual and non-visual effects of light can contribute to improving the quality of life of building users, as well as favoring their performance and commitment.

Lighting conditions in work environments contribute to a variety of factors such as mood, engagement and job satisfaction, absenteeism, productivity and well-being (BORISUIT et al., 2015). Several studies prove people's preference for natural light in the work environment to the detriment of artificial lighting. Borisuit et al. (2015) developed a research analyzing the performance of a group of volunteers in an office (test room) of 7m x 5m exclusively under natural light and exclusively under artificial light. Participants reported that alertness and well-being declined throughout the afternoon period in both types of lighting; however, under the condition of artificial lighting only, physical well-being worsened and sleepiness occurred earlier, compared to the scenario with natural lighting only.

Drowsiness after lunch is common due to the digestion process. The scientific name for this process is postprandial alkalosis and one of the hypotheses is that blood flow to the brain decreases so that the digestive system works more efficiently (VEJA, 2019). 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.

These surveys demonstrated the need to understand office typologies to enable the design of design guidelines that improve the performance of building users in relation to their well-being and circadian rhythm regulation.

Pisani and Figueiredo (2011) conducted a survey and classified the recurrent typologies of office buildings, according to the position of the vertical circulation core (core) of the building. The researchers classified the types as shown in Figure 3 below.

According to the research, of 115 buildings from São Paulo production published in the Magazine: ''*Projeto Design*", from 1979 to 2010, typology "B" is the most recurrent, with 50 buildings. In this typology, the core of vertical circulation is located on one of the facades of the building.

The United Nations Building (WTNU) building – designed by architect Edo Rocha and completed in 2008 – was selected for the survey; because, in addition to meeting the typology requirement, it had the floor layout disclosed, which brought the study closer to the reality of using an office building. Figure 4 shows the floor plan published in the magazine Projeto Design and an image of the building.

The floor plan was redesigned in AutoCAD, according to WTNU (2012) and the pavement modeling was developed in SketchUp software, where all the furniture was inserted. Only the floor-to-ceiling partitions, shown in blue, were considered to be made of transparent glass (Tvis 88%). The partitions between workstations were considered to be 0.45 m above the table. Only workstations in open space areas were analyzed in this research, in which the following dimensions were considered for modeling: ceiling height 2.80m, sill 0.80m and glass skin 2.00m. The height of the sill was found in the plan provided by WTNU (2012) and the ceiling height was considered the recurrent feature of a triple A building, which can vary between 2.70m and 2.80m.

2 Modeling of the standard floor of the selected building and insertion of the ALFA tool parameters

The standard pavement model developed in the SketchUp software was imported into the Rhinoceros 3D program and the ALFA (Adaptive Lighting for Alertness) plugin, recently launched by the company Solemma, linked to the Massachusetts Institute of Technology, MIT, was applied. The tool allows the prediction and control of the non-visual effects of light in architectural design, in order to create safer, healthier and more productive environments (SOLEMMA, 2021). It is able to 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 (illumination in the vertical plane, at the height of the users' eyes, that is, at 1, 20m from the floor). The results of the simulations

Figure 4: Floor plan of Tower 2 of the United Nations Building

Source: CORBIOLI, 2009, p. 63 e 59

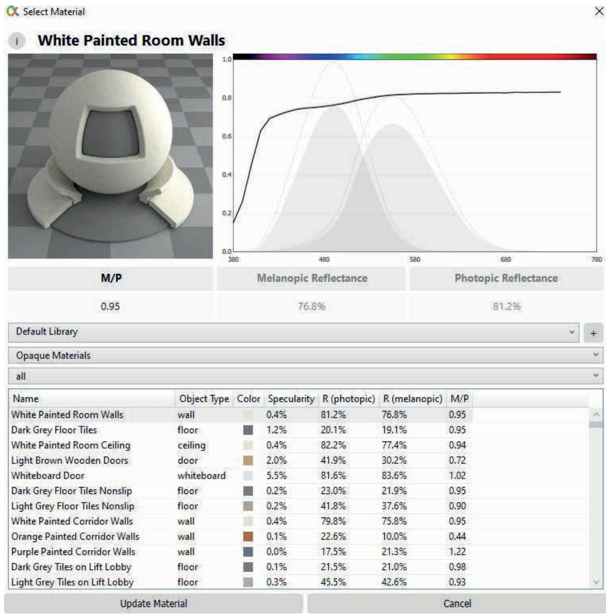

Figure 5: ALFA tool material library

Source: ALFA (2021)

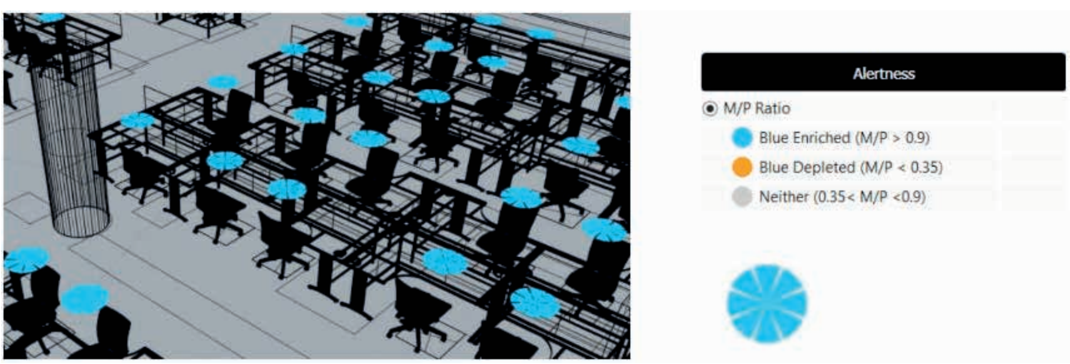

Figure 6: Pavement modeling and legend of the results

Source: ALFA (2021)

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are presented in two ways: state of alert (M/P ratio) and Equivalent Melanopic Lux (EML), which indicates the absorption of light by means of melanopsin, the photosensitive protein present in the ipRGCs receptors. 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 context of the simulation.

The library of materials available in the program has some limitations, however it brings the M/P ratio of the opaque and glassy materials, indicating that the materials must also be observed in studies related to the circadian rhythm, in addition to light. Figure 5 demonstrates part of the material library.

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 allow the distinction of colors, and photopic illuminance is the emission of light by its surface, according to Foster (2020). This relationship compares the melanotic potential (referring to ipRGCs) with the Light Source's ability to produce light appropriate for the vision of details in the daytime (photopic) (MILLER; IRVIN (2019). Research shows that the more energy is emitted in the spectral range to which ipRGCs are most sensitive (460nm to 480nm), the greater the light source warning potential (TICLEANU; LITTLEFAIR, 2020); on the other hand, the lower the M/P ratio, the better the conditions for sleep and relaxation.

This research used only the results of the state of alert (M/P ratio) for the evaluation of the floor type of the selected building. The ALFA tool considers that the alert state occurs when the M/P ratio is greater than 0.9 (blue color) and that the relaxed state (orange color) occurs when the M/P is less than 0.35. The result between 0.35 and 0.9 (gray color) was called in this research a neutral state, as the spectrum and amount of light do not affect the circadian rhythm. The view direction is represented by default, in eight distinct positions and indicated by means of a subdivided circle. The number of evaluations, in relation to the direction of vision, can be changed, according to the needs of each study. Figure 6 indicates part of the modeling of the typical pavement and the legend of the results, according to the evaluation of the M/P ratio. The program evaluates the color spectrum of light in relation to the response to the light stimulus.

For simulations with artificial lighting, luminaires measuring 0.60m x 0.60m, 48W of system power, luminous flux (system) 5400lm, efficiency of 112.5lm/W, with reflector and parabolic fins, integrated LED with color temperature of 4000 were used. K, the same color temperature used in most office buildings. The luminaires were distributed over the floor according to lighting parameters. This color temperature of light (4000K) is more stimulating for the circadian rhythm, due to its peak at a wavelength around 450nm. Figure 7 compares the spectra of four light sources: light from clear sky (color temperature 7506K, without sunlight); direct sunlight (color temperature 5503K); neutral white artificial light (color temperature 4186K) and warm white artificial light (2167K).

It is necessary to insert the finishing of all the materials in the model, during its configuration, to develop the simulation using the ALFA tool. Therefore, the finishes on the standard floor were used in accordance with the photo published in the interior of the building: ceiling, walls, pillars in white color and dark gray floor. The luminaire

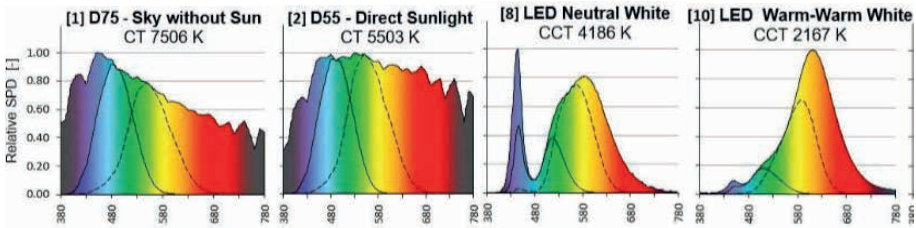

Figure 7: Spectrum of light in different light sources

Source: MAIEROVA, 2018, p. 3

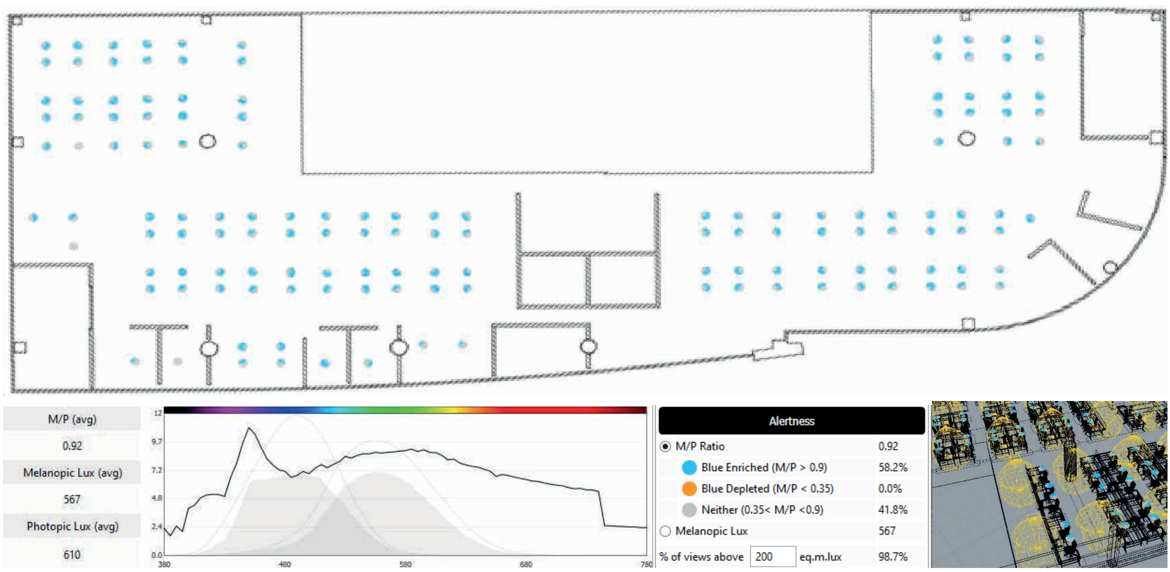

Figure 8: Simulation result with artificial lighting only

Source: Own author

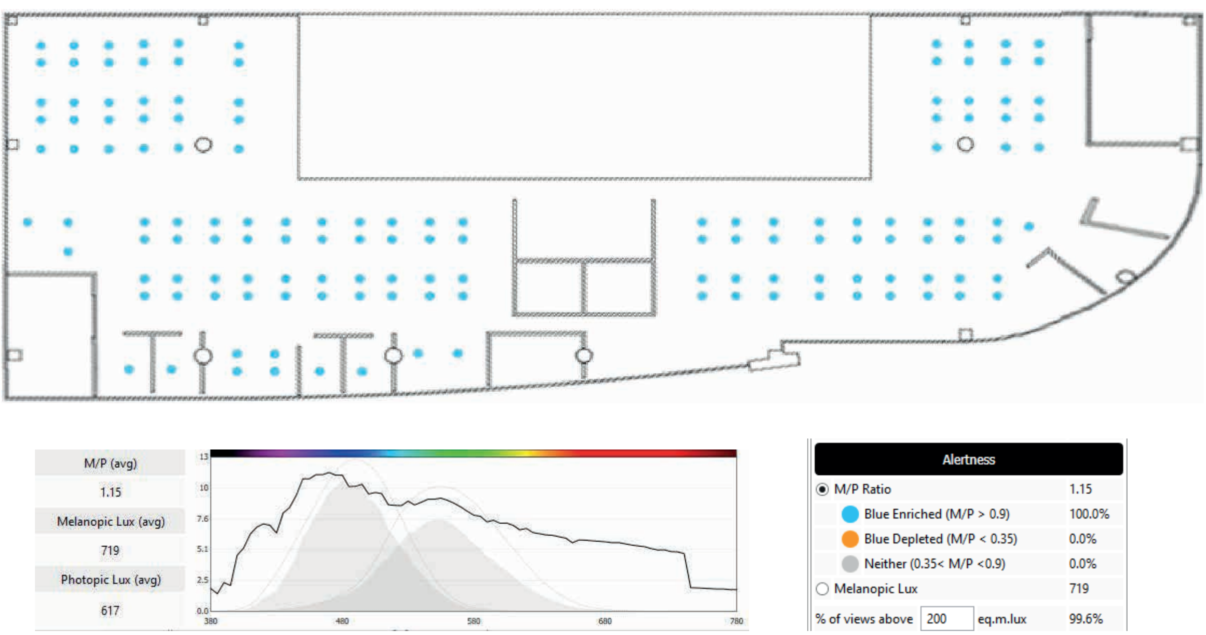

Figure 9 – Simulation result only with natural lighting

Source: Own author

used in the simulation followed the same pattern as the luminaire published in the magazine Projeto. The furniture – as well as its finishes – was chosen by the author of the research, as follows: light wood tables, black chairs; partitions between the tables (on the workstations) in white; transparent glass in the floor-to-ceiling partitions (Tvis 88%) and glass in the Tvis 26% enclosure. The exact light transmittance of WTNU glass was not found in any publications. It was assumed that this value varied between 20 and 30%, which is an average used in office buildings recently built in the city of São Paulo.

3 Simulation of the circadian performance of the standard floor of the WTorre building – Building 2 in the ALFA tool.

It is mandatory to specify a day and time for all simulations in the ALFA tool. Therefore, the simulations were developed for 9 am on 03/21, with a clear sky and sun in two different scenarios: artificial lighting only and natural lighting only. In the case of the simulation with only artificial lighting, the glass was replaced by a light colored wall, so that it was possible to make a comparison between a situation in which there was no natural lighting, such as a recurring scenario in office buildings, where the blinds can spend long periods down.

Figure 8 indicates the result of the scenario with artificial lighting only, where 58.2% of the evaluated positions are within the blue enriched parameter or state of alert and 41.8% within the neutral interval, where there is no stimulus for the rhythm circadian. The average illuminance in the work plane (photopic) resulted in an average of 785lux, in which 100% of the sensors recorded illuminance above 300 lux; regarding visual comfort, the average photopic illuminance was 610lux. It is observed that the peak of the light spectrum in the simulation is around 450nm.

Figure 9 presents simulation results with daylight only, where 100% of users' viewing directions at the evaluated workstations were above the blue enriched parameter or state of alertness. The average illuminance on the work plane (photopic) resulted in an average of 685lux, where 98.6% of the sensors registered illuminance above 300 lux, and the photopic illuminance, in relation to visual comfort, reached an average illuminance of 617lux. It is observed that the peak of the simulation spectrum is around 480nm.

RESULTS AND DISCUSSIONS

The simulations demonstrate that the average illuminance on the work plane was 100 lux lower in the simulation with natural lighting, compared to the artificial one in the simulation with the ALFA tool. However, the most stimulating light source for the circadian rhythm was natural light, where 100% of the analyzed visual directions were above 0.9 (M/P ratio).

According to Reinhart (2014), an environment with lateral lighting equipped with blinds makes it possible to reach natural light between approximately 1 or 2 times the height of the window – from the floor – and spaces with openings without sun protection elements increase the reach maximum of natural light to 2.5 times. Figure 10 indicates, in orange, the range of daylight one and a half times the height of the opening, which coincides with the height of the floor, and in yellow, the maximum range of 2.5 times the height of the height. It can be seen that most workstations are located in a range of up to 2.5 times the height of the window. The high performance of the analyzed building is justified due to the floor being shallow, where the maximum distance is 15.20m in relation to the opening.

Figure 11 demonstrates the simulation of daylighting on 03.21 at 9 am with the Relux Desktop software. The average illuminance of the pavement was very close to that obtained with the ALFA tool (660 lux) and the maximum illuminance recorded was 9,660 lux. The simulation demonstrates that the region up to 2.5 times the height of the opening has illuminance around up to 100 lux in areas without obstruction of partitions.

Andersen, Mardaljevic and Lockley (2012) made a comparison between luminous Sources and equivalent circadian illuminance and demonstrated that – to achieve the same effect in the alert state, for different Sources – many times higher illuminance is required. Figure 12 indicates that 190 lux from a D65 Luminous Source (6500K natural light) would correspond to 300 lux from a Philips 4100K lamp.

The simulations in the ALFA and Relux Desktop tools used a clear sky (D75) and, to obtain the same alert effect in the region with approximately 180 lux (natural light), 300 lux would be needed from a 4100K light source. Although the average illuminance on the work plane was higher in the simulation with only artificial lighting, the photometric distribution of the luminaire may indicate a reason for the decrease in the M/P ratio, in addition to limitations related to the spectrum of the light source.

The analysis of the reach of daylight indicated that users of the building with greater access to daylight in the morning (from 8:00 am to 12:00 am) tend to have regular circadian rhythms and, consequently, better nights sleep. These individuals – likely – will have a lower incidence of depression and demotivation, and greater well-being if the blinds are not closed.

Distances from the established rule of 2.5 times the height of the opening can help the design of buildings, indicating the best performing region for the circadian rhythm. However, illuminances above 3000 lux are likely to cause visual and thermal discomfort (NABIL; MARDALJEVIC, 2005). The excess of light identified in the study is due to a high proportion of glazed area and opaque area (window-to wall-ratio, WWR). WTNU has, with the exception of the northeast facade, 60% WWR in all its facades, which is considered excessive, according to Goia (2016) and Mangkuto, Rohmah and Asri (2016). The authors propose that a 40% ratio between glazed and opaque areas be considered – at most – for buildings located in the tropics.

External solar protections are resources that can be adopted to minimize the entry of direct sunlight and reduce glare during critical periods of the year, even when the building employs solar control glazing. The layout of the surrounding shades (Sky View Factor, FVC) is essential for the designer to find solutions for taking advantage of natural light and benefiting the building's users.

FINAL CONSIDERATIONS

From the results obtained, it is possible to verify the importance of natural light in the design of office buildings, in terms of body functions and, consequently, the health and well-being of its occupants. The ALFA tool allows the analysis of the non-visual effects of light and makes it possible to understand the light stimulus that each individual is exposed to, indoors, and the result of the calculations of the M/P ratio allows exploring the direction of vision of the users of the building and consequently estimate their behavior and well-being.

The research referenced in this work demonstrates the importance of natural lighting to obtain a regular circadian rhythm, whose effects go beyond the work environment. Individuals with – at least – four hours of exposure to natural light in the morning demonstrate better sleep at night, report less depression and less interruption during sleep. The circadian rhythm in synchrony with the light-dark periods of

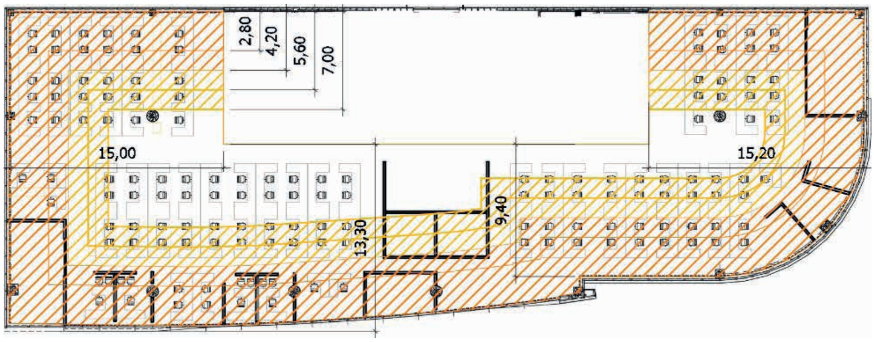

Figure 10 – Analysis of the reach of natural light, according to Reinhart (2014) and indication of the distances from the facades to the vertical circulation core (core)

Source: Own author

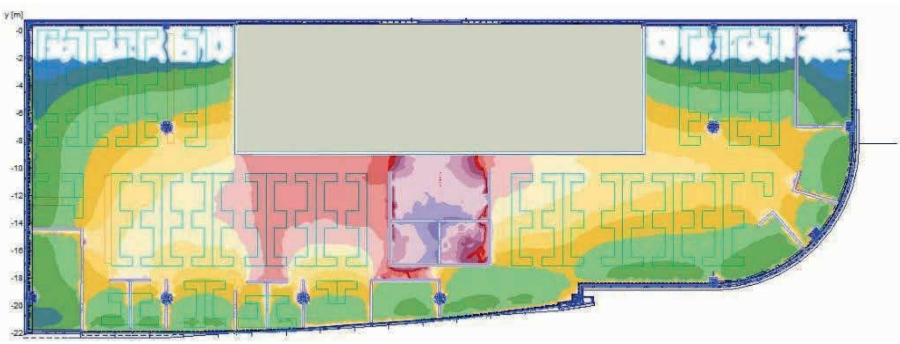

Figure 11 – Simulation of natural lighting on 21.03 at 9 am

Source: Own author

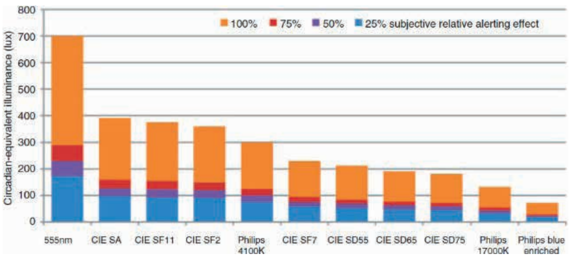

Figure 12 – Illuminance required to achieve the desired relative alerting effect for a well-known selection of illuminants

Source: ANDERSEN; MARDALJEVIC; LOCKLEY, 2012, p. 44

the outside world favors the maintenance of physiological and behavioral rhythms, benefiting the individual's performance and the feeling of well-being.

This study analyzes the most recurrent office building typology through an example (WTorre Nações Unidas, WTNU), demonstrating its circadian potential. The analysis points out that the consecrated guideline for projects that include natural lighting (up to 2.5 times the height of the opening) may also indicate the best area for occupation, in terms of the circadian rhythm of space users. However, excessive illuminance close to openings favors the use of internal blinds and reduces the use of natural lighting, which may compromise the circadian rhythm. In this scenario, there is damage to the alertness of building occupants and – in the long run – damage to health.

In order for natural lighting to become a viable resource, it is necessary that glass skin buildings use the WWR ratio according to the latitude of the city in question. It is important to evaluate not only the building itself, but issues related to the geometry of insolation, such as the Sky View Factor and the critical periods of insolation on the facades, when solar protection is indispensable.

As a continuation of this work, comparative studies will be carried out between the main typologies of office buildings and the circadian potential of each one, as well as studies that manage to delineate a proportion between glazed and opaque areas for office buildings in São Paulo.

REFERENCES

ANDERSEN, M; MARDALJEVIC, J; LOCKLEY, Sw. A framework for predicting the non-visual effects of daylight – Part I: photobiology- based model. **Lighting Research & Technology**, [S.L.], v. 44, n. 1, p. 37-53, 13 fev. 2012. SAGE Publications. http://dx.doi.org/10.1177/1477153511435961.

AOKI H; YAMADA N; OZEKI Y; YAMANE H; KATO N. Minimum light intensity required to suppress nocturnal melatonin concentration in human saliva. **Neurosci Lett**. 1998 Aug 14;252(2):91-4. doi: 10.1016/s0304-3940(98)00548-5.

BORISUIT, A; LINHART, F; SCARTEZZINI, J-L; MÜNCH, M. Effects of realistic office daylighting and electric lighting conditions on visual comfort, alertness and mood. **Lighting Research & Technology**, [S.L.], v. 47, n. 2, p. 192-209, 22 abr. 2014. SAGE Publications. http://dx.doi.org/10.1177/1477153514531518.

BROWN, T. M. Melanopic illuminance defines the magnitude of human circadian light responses under a wide range of conditions. **Journal of Pineal Research**, Nova York, v. 69, n. 1, p. 1-14, 19 abr. 2020. Wiley. http://dx.doi.org/10.1111/jpi.12655.

CORBIOLI, Nanci. Passarelas unem edifícios com áreas de laje diferentes. **Projeto Design**, São Paulo, v. 1, n. 1, p. 58-65, abr. 2009.

FIGUEIRO, M.G. NAGARE, R.; PRICE, L.L.A. Non-visual effects of light: how to use light to promote circadian entrainment and elicit alertness. **Lighting Research & Technology**, [S.L.], v. 50, n. 1, p. 38-62, 25 jul. 2017. SAGE Publications. http://dx.doi.org/10.1177/1477153517721598.

FIGUEIRO, M.G.; STEVERSON, B.; HEERWAGEN, J.; KAMPSCHROER, K.; HUNTER, C.M.; GONZALES, K.; PLITNICK, B.; REA, M. S. The impact of daytime light exposures on sleep and mood in office workers. **Sleep Health**, [S.L.], v. 3, n. 3, p. 204-215, jun. 2017. Elsevier BV. http://dx.doi.org/10.1016/j.sleh.2017.03.005.

FOSTER, Russell. How Light Exposure Affects Human Health. In: SLL LIGHTING RESEARCH & TECHNOLOGY SYMPOSIUM, 1., 2020, Londres. **How Light Exposure Affects Human Health**. Londres: CIBSE, 2020. Disponível em: https://bit.ly/32jnNlj. Acesso em: 02 nov. 2020.

FRANK, Horst. **Electromagnetic spectrum -de.svg**. 2005. Disponível em: https://bit.ly/3uBu6fU. Acesso em: 15 mar. 2021.

LOK, Corie. Seeing without seeing. **Nature**, S.L., v. 469, n. 1, p. 284-285, 20 jan. 2011. Disponível em: https://go.nature.com/3mLFseM. Acesso em: 02 fev. 2021.

GOIA, F. Search for the optimal window-to-wall ratio in office buildings in different European climates and the implications on total energy saving potential. **Solar Energy**, [S.L.], v. 132, p. 467-492, jul. 2016. Elsevier BV. http://dx.doi.org/10.1016/j.solener.2016.03.031.

KAIDA, K.; TAKAHASHI, M.; HARATANI, T.; OTSUKA, Y.; FUKASAWA, K.; NAKATA, A. Indoor Exposure to Natural Bright Light Prevents Afternoon Sleepiness. **Sleep**, [S.L.], v. 29, n. 4, p. 462-469, abr. 2006. Oxford University Press (OUP). http://dx.doi.org/10.1093/sleep/29.4.462.

LOCKLEY, Steven W.; ARENDT, Josephine; SKENE, Debra J. Visual impairment and circadian rhythm disorders. **Dialogues In Clinical Neuroscience**, [s. l], v. 9, n. 3, p. 301-3014, set. 2007.

MAIEROVA, Lenka. Public Lighting, Public Health. 2018 VII. **Lighting Conference of The Visegrad Countries (Lumen V4)**, [S.L.], v. 1, n. 1, p. 1-5, set. 2018. IEEE. http://dx.doi.org/10.1109/lumenv.2018.8521032.

MANGKUTO, R.A.; ROHMAH, M.; ASRI, A.D. Design optimisation for window size, orientation, and wall reflectance with regard to various daylight metrics and lighting energy demand: a case study of buildings in the tropics. **Applied Energy**, [S.L.], v. 164, p. 211-219, fev. 2016. Elsevier BV. http://dx.doi.org/10.1016/j.apenergy.2015.11.046.

MARDALJEVIC, J; HESCHONG, L; LEE, E.S. Daylight metrics and energy savings. **Lighting Research + Technology**. Ernest Orlando Lawrence Berkeley National Laboratory. California, 2009.

MILLER, N.J.; IRVIN, A.L. M/P ratios – Can we agree on how to calculate them? **IES: Illuminating Engineering Society**, [S.I.], 27 set. 2019. Disponível em: https://bit.ly/2RmXqIF. Acesso em: 15 mar. 2021.

NABIL, A.; MARDALJEVIC, J. Useful daylight illuminance: a new paradigm for assessing daylight in buildings. **Lighting Research & Technology**, [s.l.], v. 37, n. 1, p.41-59, 1 jan. 2005. Cambridge University Press (CUP). http://dx.doi.org/10.1191/1365782805li128oa. Disponível em: < https://bit.ly/3dV3KyL>. Acesso em: 12 abr. 2021.

OYAMADA, Maria Kiyoko. Fototransdução: ativação, inativação e adaptação. **Rbm Revista Brasileira de Medicina**, São Paulo, v. 1, n. 1, p. 68-72, 20 nov. 2015. Disponível em: https://bit.ly/3235P6g. Acesso em: 08 mar. 2021.

PISANI, Maria Augusta Justi; FIGUEIREDO, Erika Ciconelli de. Edifícios de escritórios em São Paulo: tipologias de 1979 a 2010. **Anais 11ª Conferência Internacional da LARES - Latin American Real Estate Society**. São Paulo: EDUSP, 2011. 1-12.

REINHART, C. **Daylighting Handbook I**. USA: MIT, 2014.

REA M.S. Window blind occlusion: a pilot study. **Building Environment**, 19, 1984, p. 133-7.

SOLEMMA. **Adaptive Lighting for Alertness**. 2021. Disponível em: https://www.solemma.com/alfa. Acesso em: 15 fev. 2021.

TICLEANU, C; LITTLEFAIR, P. **Circadian lighting**. Londres: CIBSE, 2020. 30 p.

VEJA. **Entenda por que você fica com sono depois de comer**. 2019. Disponível em: https://bit.ly/3d9gTVV. Acesso em: 23 mar. 2021.

WTORRE NAÇÕES UNIDAS. **O edifício**. 2012. Disponível em: https://wtnu.com.br/estrutura.php. Acesso em: 24 jan. 2021.

ZAIDI, F.H.; HULL, J.T.; PEIRSON, S.N.; WULFF, K.; AESCHBACH, D.; GOOLEY, J.J.; BRAINARD, G.C.; GREGORY-EVANS, K; RIZZO, J.F.; CZEISLER, C.A.

Short-Wavelength Light Sensitivity of Circadian, Pupillary, and Visual Awareness in Humans Lacking an Outer Retina. **Current Biology**, [S.L.], v. 17, n. 24, p. 2122-2128, dez. 2007. Elsevier BV. http://dx.doi.org/10.1016/j.cub.2007.11.034.