The biologic clock a new approach for daylight design

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Abstract

For many years designers are not looking under the right rocks when trying to link light to human being performance. Natural light either direct or indirect has an impact on the human body and health. This paper elaborates indirect effect of daylight. Based on the rapidly emerging science of circadian photobiology, there is much more function to light than mere vision.

Introduction

The circadian rhythms is diverted from the Latin words circa (about) dian (a day), the circadian rhythm (system) is the twenty-four-hour cycle of light/dark, wakefulness/sleep to which most human physiologic processes are set.[9]

This includes cycles such as sleep/wake cycle, body temp, hormone production and alertness. At regular intervals each day, the body tends to become hungry, tired, active, listless, and energized. Body temperature, heart-beat, blood pressure, hormone levels, and urine flow rise and fall in this relatively predictable, rhythmic pattern - a pattern initiated and governed by exposure to sunlight and darkness. A master clock in the suprachiasmatic nucleus (SCN), located in the hypothalamus of the brain, regulates various circadian rhythms. [4]

Many architects generally do not know the impact of neglecting circadian rhythms as visual perception differs from circadian perception. They design deep plan, low ceiling, and give artificial light a bigger role than it should be given. Different scenarios have demonstrated that without adequate daylighting at the workplace, the correct net daily positive phase shift is difficult to achieve.

To duly consider the circadian system in the daylight design process, it is important that the melatonin hormone would be given the chance to infuse in the blood stream. Circadian system operates slower, mainly because it relies on infusion of the hormone melatonin into the blood stream, to communicate to various systems in the body. Melatonin system is disturbed by waking up late, modern science [11] has found that bright morning light synchronizes the circadian system, and if the intensity of light reaching the retina is too low, the implications are far-reaching.

It is important in the design process to reconsider the window area and orientation to let in a considerable quantity of light. A question is held "How much light does it take to affect the circadian system of building occupants?, taking into consideration that light levels required to achieve melatonin suppression is much higher than those required for vision.

In this respect, Rea [12] mentions some facts;

a. The quantity of light expressed, is in terms of illuminance. For light sources commonly used in offices, schools and homes, errors in spectral characterization of light for the circadian system can be as much as 3:1 for the same measured illuminance (lux), for example daylight is approximately 3 times more effective for the circadian system than 3000 k fluorescent lamp.
b. In 2002, Rea had reasoned the previous on the ground of the photopic luminous efficiency function based upon the spectral sensitivity of the L (long wavelength) and M (middle wavelength) cones in the human fovea. Since these two photoreceptors are essentially irrelevant to circadian phototransduction. As recent researches have shown that the physiology of the circadian photoreceptors is different from that of the visual photoreceptors. [12]

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c. Illuminance is the quantity of light falling on a surface, not how much light is made available to the retina. Depending upon the orientation of the illuminance meter, horizontal on a work plane or vertical near the plane of the retina, the same amount of light emitted by a light source can produce variations in measured illuminance of as much as 30:1. For the same illuminance, retinal illuminance can vary substantially depending upon both environmental and individual differences. [12]

The quantity of light needed for the visual system is moderate compared to the needs of the circadian system. Figure (1), shows how light levels affect visual performance and melatonin suppression.

The left-most curve labeled relative visual performance (RVP) represents the speed and accuracy of processing high contrast, alpha-numeric text by the fovea of young adults. Even under moonlight, visual performance remains relatively high when reading black print on white paper, and, as shown higher light levels results in only slight improvements. [12]

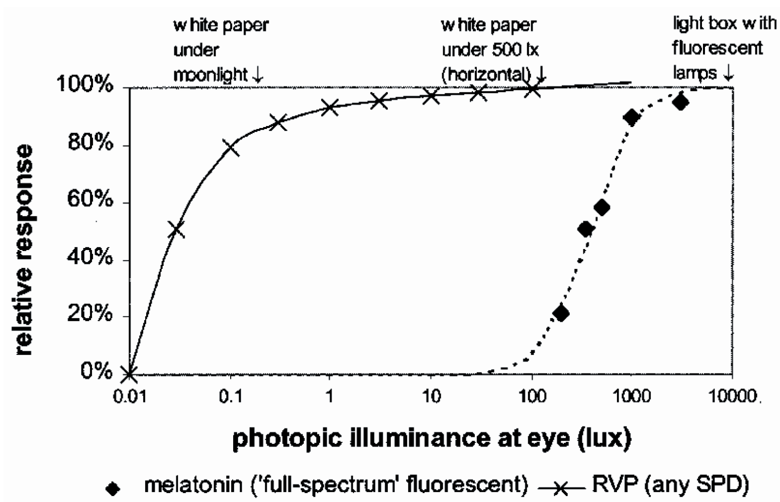


Figure 1, Relative visual performance for high contrast reading material, and relative melatonin suppression by light as a function of illuminance at the eye. [11]

In figure (1) the curve labeled "melatonin suppression"[11] is a dose–response curve, relating light to acute melatonin suppression at night. It shows that illuminances of around 100 to 200 Iux (at the eye) from "full-spectrum" lamps measured at the eye can suppress melatonin to some degree.

Healthy lighting should address the needs of both the circadian system which has been linked to sleep disorder, seasonal affective disorder (SAD) and depression on one hand, and the visual system, in terms of migraines and eyestrain in the other hand.

Although it is clear that light is the primary stimulus for the circadian system, the characteristics of light (i.e., quantity, spectrum, distribution, timing and duration) are important for the circadian system. However, the lighting needs by the visual and circadian system are so different. It seems possible to use architectural means to design healthy lighting to serve both, for example use uniform bluish light to light the ceiling, which will support the circadian function and use warm color finishes on the walls or at the task surfaces in order to accommodate the visual system. What follows is an analysis of these light characteristics from the perspective of a lighting designer.

1) Light characteristics of circadian systems

1-1) Quantity

The most obvious difference between electric light and daylight is that daylight is usually much more intense. Natural lighting levels during the day are typically much higher than those provided by electric light, [11] because it is common for light in the window environment to exceed 300 lux at the eye.

What is remarkable to consider is that a one hour exposure to typical light levels found in office environments (500 lux from white light on the workplane) are sufficient for the visual system to process most alpha-numeric information. [11] This intensity of light is barely sufficient to stimulate the circadian photobiological system which requires greater quantity of light, independent of distribution. However, as the body (circadian system) requires higher quantity of light we can be rest assured that the eye will get its share.

The previous suggests that interior lighting levels, as currently recommended and practiced, may be insufficient for circadian regulation. It is clear that significance of access to daylight brighter than that recommended for the visual performance, at least for certain duration in the morning is very important. The facilities, the architect can practice to duly consider the gaining of building occupants adequate quantity of daylight, vary. The occupants have to be close enough to a window to receive high levels of illuminance (in excess of 1000 lux), which is rarely experienced in artificial lighting. This requires demands on the planning and external envelope, shallow plans, as well as the management of space.

From the health benefits of proximity to windows is the exposure to morning strong light, and access to views. The access to views is important for occupants' health, especially if the view is of trees and parkland as well as clouds and sky and other natural features, for example the proximity of the table to the window in the Jaech Residence, figure (2). In this example, the glazing area extends the inside to outside and provides expansive vistas of the water and landscape. [8]

Figure 2, Jaech Residence. [7]

1-2) Spectrum

The spectral composition of natural light is different than most electric light. Figure (3) shows the Spectral Power Distribution (SPD) of daylight and those of several common electric light sources. Electric light sources used for interior applications are designed to maximize the conversion of electric power into visible radiation. [11]

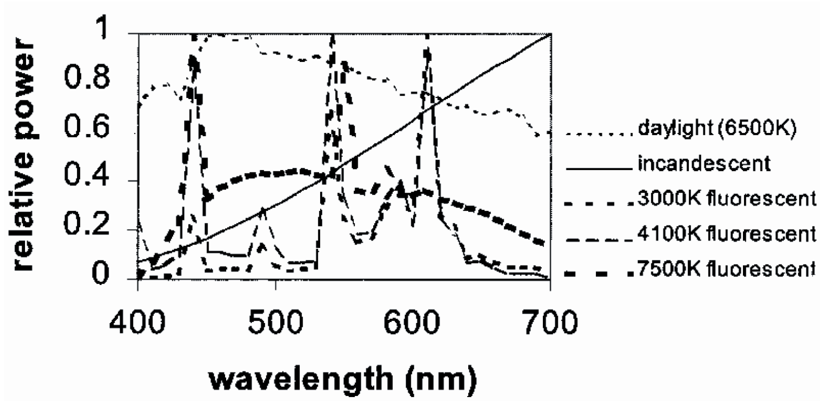


Figure 3, Spectral power distribution for several light sources; daylight, incandescent lamps, and 3000 k, 4100 k, and 7500 k phosphor fluorescent lamps. [11]

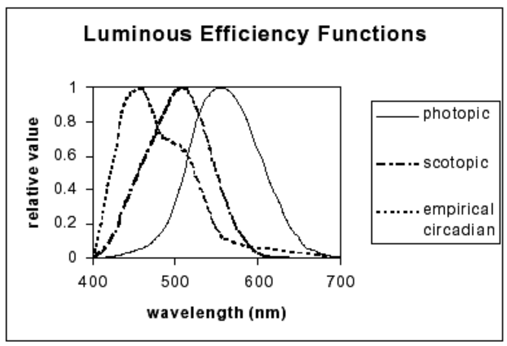


Figure 4, Photopic and scotopic luminous efficiency functions, as well as an empirically derived action spectrum for melatonin suppression. [7]

The spectral sensitivity of the circadian system C(λ) is very different from the spectral sensitivity of the fovea, which used to perform nearly all of our visual work. In other words, the visual system, figure (4), is most sensitive to the middle wavelength portion of the spectrum with a peak sensitivity of 555 nm, which results in a generally warm light, while the photobiological (circadian) system is responsive to the short wavelength portion with peak sensitivity of 420-480 nm [5], perceived as bluish light [13].

For example, at 500 lux on the workplane, a 7500 Kelvin (k) fluorescent lamp is almost 2.5 times more effective in melatonin suppression (1 hour exposure) than a 3000 k Fluorescent lamp because on the color temperature scale it is cooler. In other words the 7500 Kelvin (k) fluorescent lamp emits shorter wavelength light than that is emitted by the 3000 k Fluorescent lamp, and this appears from figure (5). In term of visual performance they are the same, even though the 7500 k lamp would probably appear brighter. [7]

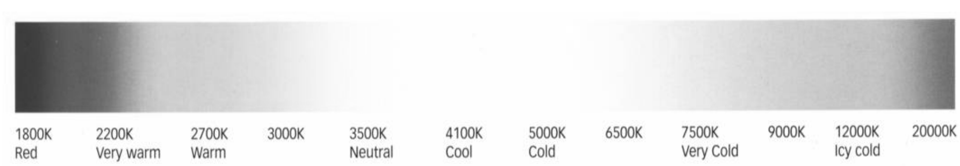


Figure 5, Color temperature (Apparent color of scene). [9]

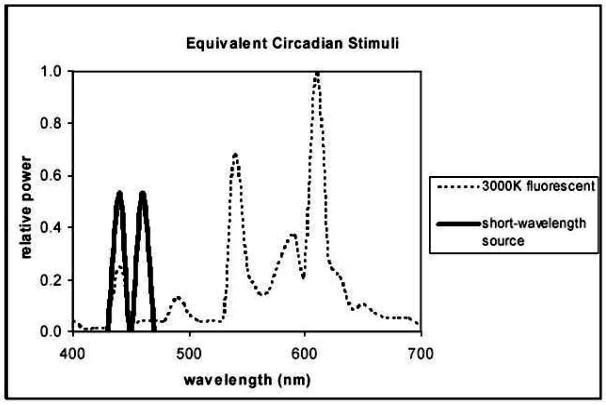


Figure 6, Relative spectral power distribution of a 3000k fluorescent lamp and a short-wavelength source for equivalent circadian effect. [6]

The photopic luminous efficiency function is, however, based on the spectral sensitivity of a very small fraction (1–2%) of the photoreceptors in the eye [10], these photoreceptors are largely unimportant, however, to circadian photobiological effects. Mariana [6] mentions that, the function named circadian spectral sensitivity (C(λ)), is a combination of rod and S (short wavelength-blue) cone spectral sensitivity.

These findings are significant because they show how light sources that have been designed to meet the needs of the visual system, like the 3000k fluorescent lamp (figure 6), are not very effective in activating the circadian system.

It can be concluded that light sources with maximum emission [7] at the short wavelengths will have a greater impact on the circadian system than light sources with maximum emission at longer wavelengths. These findings open the door for optimizing the use of light in both therapeutic and architectural application.

The relative ratio of circadian to photopic lumens for daylight is 2.78. This ratio provides estimate of the relative error that would be made in determining the effectiveness of daylight as light sources on the circadian system when a conventional light measuring device (photometer) employing a photopic (V_λ) luminous efficiency function is used.

1-3) Spatial Distribution

The circadian system does not respond to the patterns of light distribution, only the overall amount of light reaching the retina. For the visual system, light distribution is critical to visual performance. A research has reported that, the lower area of the retina, where the image of the sky is formed, is more sensitive to light and thought to contribute more to the circadian system. Light pattern not light distribution is important, only to be sure that light will incidence on the lower area of the retina.[13]

Use uniform bluish light, to light the ceiling, which will result in illuminance predominantly on the lower retina without visual discomfort. To accommodate the visual system, have warm color finishes on the walls or at the task surfaces. The renovations of the Sterling Memorial library at Yale University include conversion of an existing open-air courtyard into a new multilevel music library, figure (7). Clerestories on all four sides of the space provide reflected indirect light onto lightly bluish colored ceiling, and consequently the light is reflected in the space below. The gothic-inspired, arched trusses are rendered in bluish color. This light pattern addresses circadian system; result in illuminance predominantly on the lower retina without visual discomfort. The wooden furniture and wood coated walls are rendered in warm colors, which accommodate the visual system.

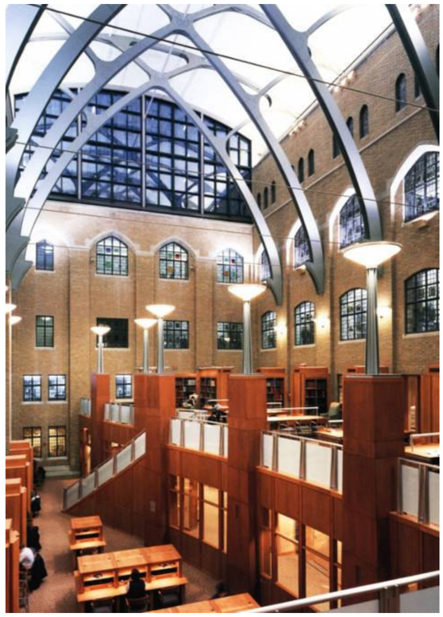


Figure 7, Overview of the music library addition at Sterling Memorial library. [3]

1-4) Timing

1-4-1) Positive/Negative phase shift

The temporal characteristics of light are particularly important to the circadian system and must be considered in any system of circadian photometry. Depending upon the time of exposure, light can phase advance, phase delay or have no impact on the timing of the circadian clock.

The pineal gland is much more sensitive early in the morning than during the middle of the day, as is shown in figure (8) of Kronauer model [1]. Kronauer has made a model of human sensitivity to light exposure in relation to phase shifting (shortening/lengthening) of circadian cycle. This model shows that:

a. At peak sensitivity (at about 4 am), even low-intensity light can result in a positive phase shift, but as the day progresses, this sensitivity gradually declines, so that higher and higher light intensity (and/or longer duration) is required to have the same effect.
b. There is a crossover point (at about 2 pm), after which exposure to strong daylight increasingly slows circadian rhythms down again (i.e. resulting in negative phase shift).

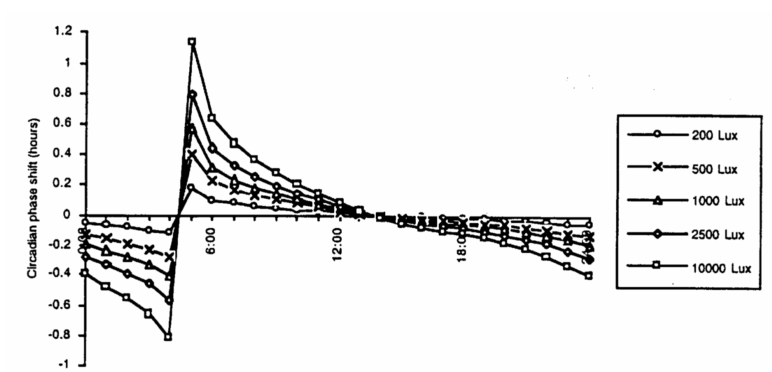


Figure 8, Kronauer model. [1]

Mark [11] explains in the figure (9), how light exposure affects the timing of the biological clock;

a) Phase delay: If light is applied during the early night (the first half of the night), the biological clock is reset to a later time
b) Phase advance: when light is administered in the late night/early morning (light applied in the second half of the night), this issue will reset the biologic clock to an earlier time. Bright light before 10 AM, from daylight helps reset the biological clocks.

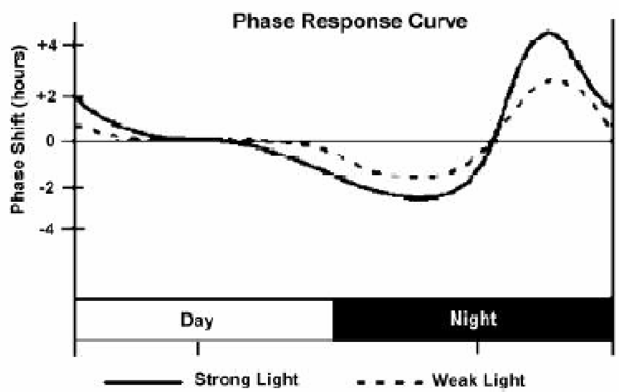


Figure 9, The effect of the time of light application on phase shifting of the core body temperature rhythm for two different light levels. [11]

Figure 10, Library at the James Madison School of Excellence. [1]

Because the human's clock's natural rhythms is a bit longer than 24 h, we need to advance it every morning in order to be synchronized to the solar day.

Occupants must be close to the north side and the east side windows and receive equal opportunities for adequate exposure, this puts considerable constraints on layout planning and utilization of available spaces. In James Madison School of Excellence, the library is occupied in the east side, this enhances the ability of the students to be subjected to morning light quantity and quality, figure (10). The upper surfaces are in light colors, but the human scale zone is in warm colors. The great window area illuminants the space with daylight where all light spectrum is available, and this leads to the support of the circadian system.

1-4-2) Daylight timeline and orientation

The latest photobiological researches have shown that the lighting timeline along the day affecting our biologic (circadian) system, is not homogenous, but the timeline changes along the day; with the progress of the day the amount of illumination needs to be reduced.

The morning bright light should exceed 1000 lux at the eye and after 2:00 PM the daylight quantity should not drop below the minimum required for the different tasks, for good visual performance. This study was established in search for the capabilities offered by each orientation for the abundance of daylight timeline along the day, in Egypt (Cairo at 30° N).

In this respect, a model was designed within a number of parameters of the Egyptian building code (Law 106/1976 on the regulation of the construction works) that governs building works have stipulated that the enclosed area for residential rooms and for offices should not decrease that 10 m^2. The minimum width should not drop below 2.7m. The clear internal height should not also decreases than 2.7m.

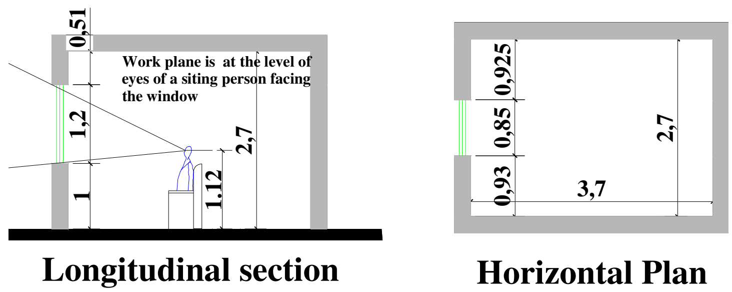


Figure 11, The Model.

The residential room that is selected for this study is a 10 m^2 room, measuring 2.7 x 3.2 m, and this is the minimum limits and requirements for the above Egyptian building regulations. The internal height of the room is also the minimum for residential rooms (2.7 m), and the window is in the center of the width of the room, figure (11). The internal room reflectance for ceiling, internal walls, and internal floor are 75%, 60%, and 15% respectively.

In this study, the model will be calculated and analysis for variable time and configurations namely, summer solstice (June 21), and winter solstice (December 21), for the four orientations during daytime hours; 8:00 AM, 10:00 AM., 12:00 AM., 2:00 PM, and 4:00 PM.

The model can be tested using manual calculations [4], computer tools, and physical scaled model. It was found that the first and last tools were time consuming, so the computer software (Ecotet v5.20) was used for testing.

The computer tool was calibrated with the manual calculations to verify if it harmonizes with manual data. The average deviation between program result and manual calculation for the four major orientations, at 11:00 AM (winter solstice) and at 3:00 PM (summer solstice), at the center of the room, is 8.1%, figures (12 and 13). Therefore, we can deduce that the program corresponds with the manual calculations.

The results were very encouraging at the center of the room for the east orientation rather than the north, south, and west orientation. It was found that the east orientation is the only direction where the daylight timeline is graduated naturally and reduced by the progress of the day, from 1895 lux at 8:00 AM to 352 lux 4:00 PM in summer solstice, and from 881 lux at 8:00 AM to 104 lux 4:00 PM in winter solstice, which coincides with the human body circadian and vision needs.

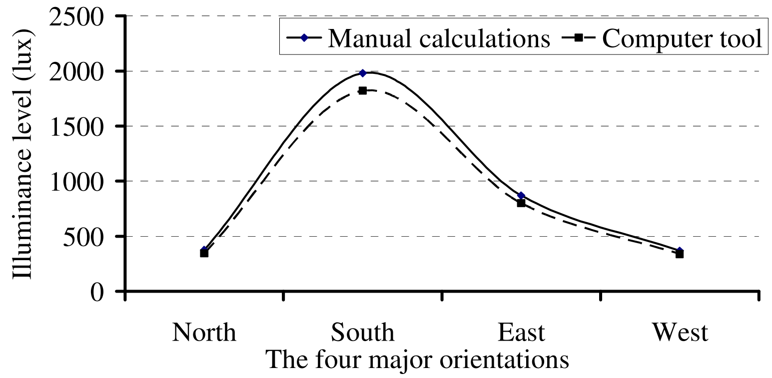


Figure 12, Manual calculations and computer tool results for winter solstice (11:00 AM)

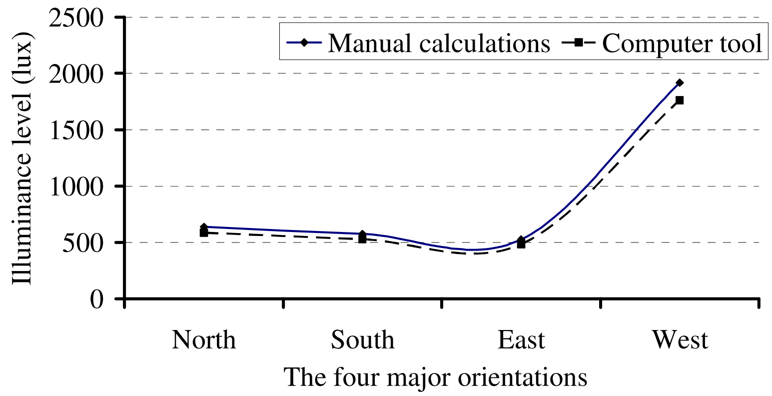


Figure 13, Manual calculations and computer tool results for summer solstice (3:00 PM)

In summer season, the curve of daylight timeline of east orientation through the day concedes with the human circadian system needs, starting with high illuminance levels and gradually decreases, figure (14). While the north and south orientations concede with the circadian systems needs in the afternoon, and the west orientation is completely vise versa to the circadian rhythms needs.

In winter season, the curve of daylight timeline of east orientation through the day also concedes with the human circadian system needs, starting with high illuminance levels and gradually decreases, figure (15). While the north orientation also concedes with the circadian systems needs in the afternoon, and the west orientation is again vise versa to the circadian rhythms needs through the day, and the south orientation reaches its high illuminance at 2 PM and this does not concedes with the circadian rhythms requirements.

Therefore, the East facade is of prior importance, east facing apertures should be as always as possible be in most designs. There importance lies in achieving the required daylighting levels even if for a while in morning hours, then start graduating the daylight intensity through the rest of the day adjoining with the north and south orientations in summer, and South orientation in winter, figure (14 and 15).

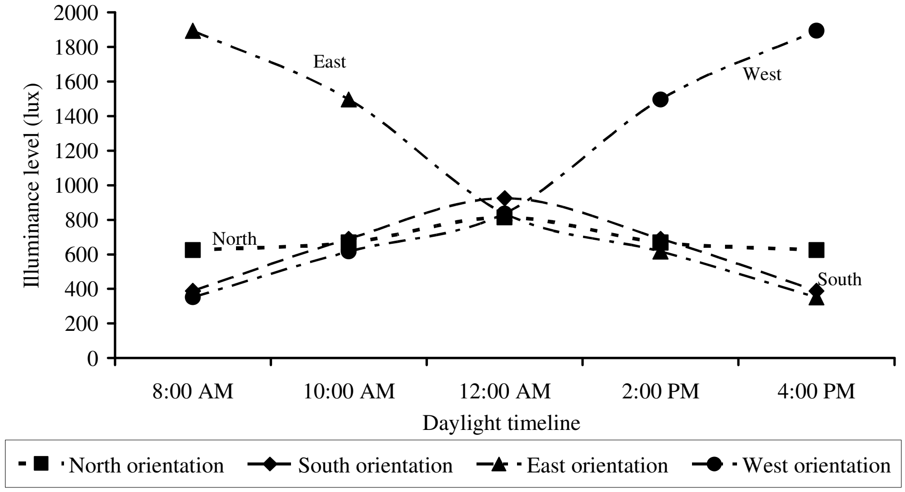


Figure 14, Illumination at eye and daylight timeline in summer

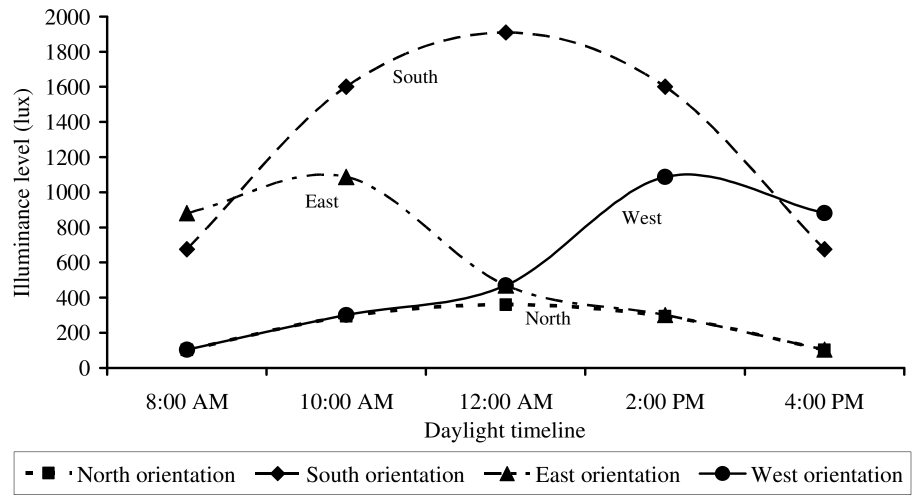


Figure 15, Illumination at eye and daylight timeline in winter

1-5) Duration

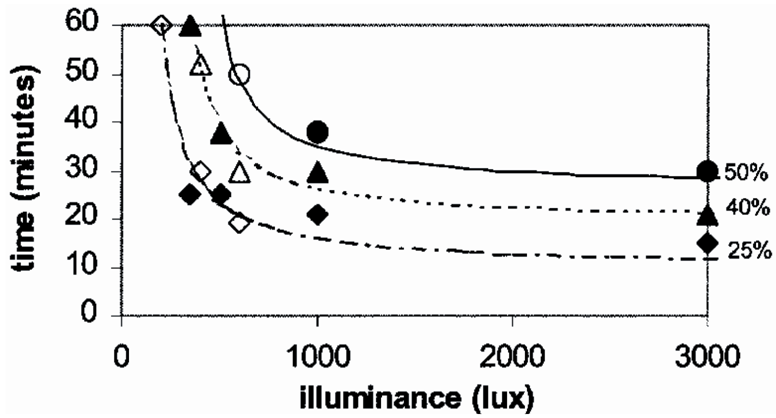
The circadian system operates slower mainly because it relies on infusion of the hormone melatonin into the blood stream. The human's initiative duration of melatonin suppression contents in bloodstream is approximately 10 min after bright light exposure had been initiated. The initiative duration of melatonin to return to its nocturnal levels after extinguishing light will be within at least 15 min. [12]

A study [12] made for, three different levels of melatonin suppression (25%, 40% and 50%) where the relationship between illuminance at the eye and the time that melatonin could be measured at these levels of suppression, figure (16). This study under its testing conditions found that:

a. Twenty-five percent melatonin suppression could be measured in less than 20 min. as long as the sustained illuminance at the eye was greater than 1000 lx.
b. If the illuminance at the eye decreased below 500 lx, it could take up to an hour to suppress melatonin by 25%.

c. Also a relatively low illuminance of 200 lx at the eye will never result in melatonin suppression greater than 25%, no matter how long it is presented.

Thus depending upon the time and duration of exposure, light can has positive or negative phase shift impact on the timing of the circadian clock (melatonin suppression).



Circles represent 50% suppression Triangles represent 40% suppression Diamonds represent 25% suppression

Figure 16, The amount of time required to measure human nocturnal melatonin suppression by light, as a function of the illuminance provided at the eye. [12]

2) Design guide

In the hope of finding some sort of relationship between daylight factor at the center of the room and daylight quantity needed by circadian system to be a guide at the primary stage of design, a relation was found and calculated between:

a) Daylight factor at the center of the rooms that have similar proportions (the minimum requirements for residential rooms in the Egyptian building code).
b) Average room reflectance (Walls, Ceiling, and Floor)
c) Percentage of window area to room area. (WA/RA)

In this respect, a design guide was accomplished within a number of parameters:

a) Window areas have been taken for 6 different sizes; 1, 2, 3 and 4 m^2, such that the window area does not fall below 8% of the floor area, with a minimum area of 1 m^2, as stated in the Egyptian building code.
b) The window sill and lintel are of dimensions regularly used in most of the Egyptian residential projects. The sill (1 m), and the lentil (2.2m) are kept constant, and the window is positioned in the center of the external wall, with a width ranging from 0.8 to 3.3 m, see table (4).
c) The room area ranges from 10 m^2 to 30 m^2, table (15). (The minimum requirement for room area in the Egyptian building code is 10 m^2).
d) The room ratio is **1 : 1.37**, represents the minimum required dimension of a room stated in the Egyptian building code with a minimum width of 2.7 m. The room height (2.7m) is constant, the reference position is at the center of the room at 1.12 m from the internal floor level, representing the eye level of a person sitting on a chair facing the window.
e) Internal wall reflectance is 40, 50, and 60 %.
f) Ceiling reflectance is 50, 60, 70, and 80 %.
g) Floor reflectance is 15 %.
h) Glass reflectance is 15 %.

			Room area m² (ratio = 1:1.37)					
			10	14	18	22	26	30
Room Dimension (m)	Width		2.7	3.2	3.6	4	4.4	4.7
	Length		3.7	4.4	5	5.5	6	6.4
Window area (m²)	1 m²	W	0.85	0.85				
		H	1.2	1.2	1.2	1.2		
	2 m²	W	1.6	1.6	1.6	1.6		
		H	1.2	1.2	1.2	1.2	1.2	1.2
	3 m²	W	2.5	2.5	2.5	2.5	2.5	2.5
		H	1.2	1.2	1.2	1.2	1.2	1.2
	4 m²	W			3.3	3.3	3.3	3.3
		H			1.2	1.2	1.2	1.2

Table 1, The models areas and windows.

The results from the previous different parameters were obtained through running the computer program (calibrated previously). A relation ship was obtained between the percentage of window area to room area (WA/RA), average room reflectance, and the daylight factor, plotted together in a design guide manner, figure (16).

A relation ship was also obtained between the ceiling and internal walls surface reflectivity, and average internal room reflectance for all the previous parameters used, taking the minimum proportions of rooms and minimum requirement for window area, stated in the Egyptian building code. The average room reflectance can be obtained, figure (14), once knowing the ceiling and internal walls reflectivity.

The design guide can be used for any room area within the minimum proportions of Egyptian building code. For example a residential room oriented east, its window area to room area is 0.12, and ceiling, and walls reflectivity is 75, and 50 % respectively. The calculation time is 11:00 AM, in summer solstice;

1) Find the average room reflectance from figure (17), through knowing the wall and ceiling reflectivity, starting:

1-a) Identify the ceiling surface reflection (75 %) on the **X** axis, and protrude upwards until interesting with the curves represents the internal walls surface reflectivity of 50 %, figure (17).

1-b) Extend horizontally a line from the previous cross section till coinciding with the **Y** axis, figure (17). The average internal room reflectance is 47 %.

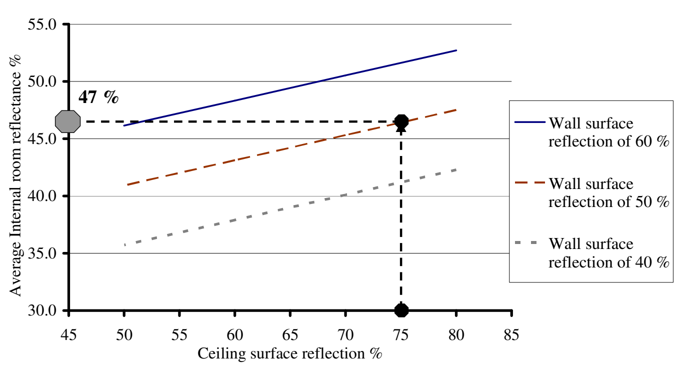


Figure 17, Average internal reflection curve.

2) The average room reflectance is known, approach the design guide curve, identify the average room reflectance on the X axis and extrude a line upward till intersecting with the percentage of window area to room area (WA/RA=0.12), and extend horizontally the line from cross point to the Y axis to obtain the daylight factor at the center of the room, figure (18). The daylight factor is 3.85 %.

3) Calculation timing is 11:00 AM, in summer solstice, and the room is east oriented. The design sky (Vertical sky illuminance) for the orientations and time required (Appendix 2), is 28500 lux. The illuminance at the center of the room is calculated by simply multiplying both the daylight factor obtained from the design chart and design sky (Vertical sky illuminance) for the orientation and time required. The illuminance at the center of the room was 1097 lux.If the quantity is found to be below than that needed for the human circadian system (≈ 1000 lux at the eye), a quick redesign process can be accomplished to obtain the best ratio of window area to room area, and internal room surface reflectance, to upgrade the illuminance level to the circadian system requirements of quantity of light.

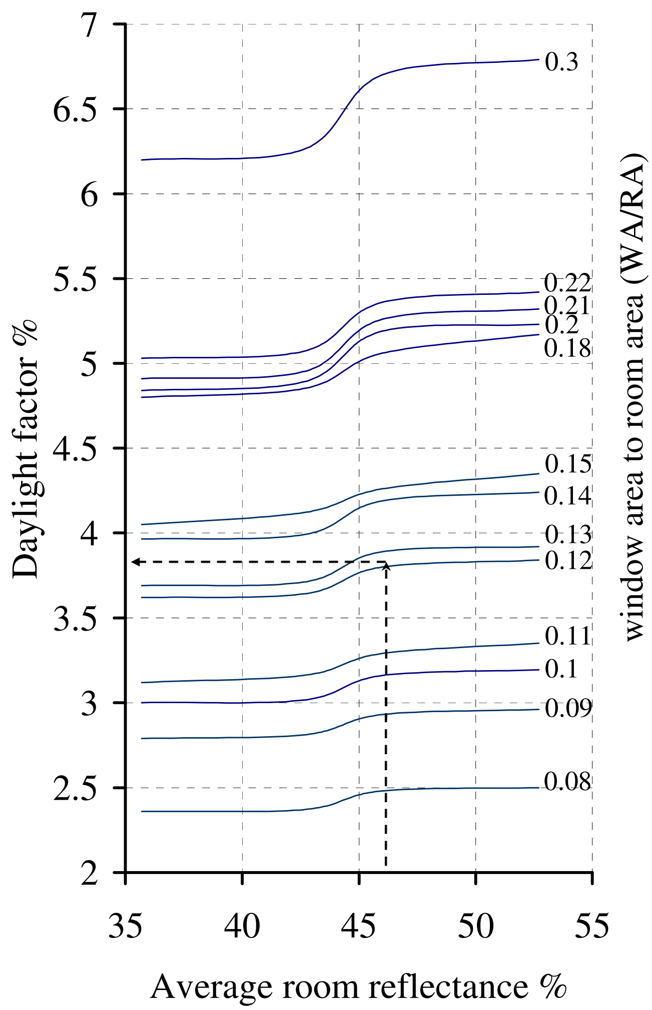


Figure 18, Relation between Average room reflectance, Daylight factor, and pecnentage of window area to room area (colord lines).

3) Results

1) The asymmetry of the phase-shifting cycle which affects the circadian system rather than the vision system, needs special care in deign. For day-shift, figure (18), the following lighting system is recommended:

a) The main daytime lighting source, which supports the vision, and circadian performance, should be from natural daylight.
b) The best way to daily entrain (reset) our circadian clocks and stimulate our bodies to produce a healthy dose of Vitamin D is 1-2 hours (complete activation duration) of exposure of a minimum of 1000 lux (starting quantity) of natural light each morning (duration of exposure is inversely proportional to quantity of illuminance at the eye). This exposure should not drop below fifteen minutes under any circumstances. The design of the aperture system thus, must fulfill the previous considerations.
c) The daylight quantity can be reduced (even after 2:00 PM) such that the quantity of daylight enclosed in the space is enough to support vision system. So it is better to use either manual or automatic controlled shuttles, this light mechanism will boost worker's alertness and performance. Where windows in office spaces are not possible, non-glare, bright, full-spectrum artificial white light should be used so as to entrain the circadian clock to daytime.

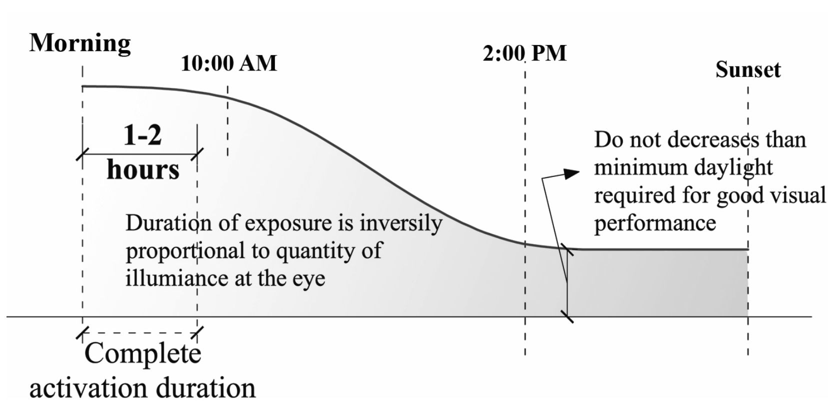


Figure 19, Daytime lighting system.

2) Concerning the circadian system, the light pattern not the light distribution is important, only to be sure that light will be incident on the lower area of the retina. Concerning this subject some daily healthy lighting design guidelines should be provided:

a) Increase the upper surface illuminance in spaces of insufficient light levels or no daylight contribution. Use indirect lighting to illuminate the ceiling.
b) Use uniform bluish light, to light the ceiling, which will result in illuminance predominantly on the lower retina without visual discomfort. To accommodate the visual system, have warm color finishes on the walls or at the task surfaces.
c) Increase the light/ dark signal to the retina, by lighted ceilings and upper walls, and dimmer or patterned (light and shadow) lower surfaces. The light dark signal can be achieved by adequate contrast.

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The biologic clock a new approach for daylight design

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ملخص

لعقود كثيرة لم ينتبه المعماريون للعلاقة الحقيقية بين الإضاءة و آداء جسم الانسان. فالإضاءة الطبيعية لها تأثير مباشر و غير مباشر على صحة جسم الانسان وتختص هذة الدراسة بدراسة التأثير الغير مباشر على صحة جسم الانسان. إستنادا الي علم سيركاديين فوتوبيولوجي لا يقتصر تأثير الإضاءة فقط علي الرؤية إنما يمتد ليؤثر ايضا علي الدورة البيلوجيه (circadian rhythms) لجسم الانسان.

[2] إدارة الأشغال ، هيئة قناة السويس

Natural light either direct or indirect has an impact on the human body and health. This paper elaborates indirect effect of daylight. Based on the rapidly emerging science of circadian photobiology, there is much more function to light than mere vision.

Visual performance, rather than circadian function, has been the primary concern of most of architectural lighting systems. The light characteristics[3] needed for vision are so different from those needed for circadian[4] functioning, and providing a healthy environment in buildings needs special daylight design schemes. This paper tackles human health and deals in particular with the eye and the effect of light on the circadian rhythms, together with the aging factor. A computer model is established within the minimum room and apertures stated in the Egyptian building code, it is found that east is the best orientation that gives daylight timeline along the day, which concedes with the circadian and visual systems needs along the day.

The computer model is also used in finding some sort of relationship between daylight factor at the center of the room and daylight quantity needed by circadian system to be a guide at the primary stage of design.

At last, better natural lighting practice should begin now. Design guidelines regarding the circadian rhythms, are stated. They major the role of daylight as a source of light. For the circadian system, the light pattern not the light distribution is important, only to be sure that light will be incident on the lower area of the retina.

[3] Light characteristics: amount of light, its spectral composition, spatial distribution, timing and duration

[4] Circadian rhythms: From the Latin circa (about) dian (a day), the circadian rhythm is the twenty-four-hour cycle of light/dark, wakefulness/sleep to which most human physiologic processes are set. Light exposure regulates several circadian functions in normal human including the sleep-wake cycle.