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Improvement of the Psychological Lighting Effect Assessment in the Environmental Building Rating Systems

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Green Architecture is not only about the way of controlling the resources consumption within sustainable limits, but it also emphasizes the positive effect on the different human requirements including his physiological sides. People spend a lot of time indoors under artificial lighting that usually lacks the dynamism and biological effect of daylight. Dynamic lighting, as an application of circadian lighting, has been used and studied in several buildings' functions with different scenarios to achieve better human performance and wellbeing. This article shed a light on the importance and the way of including the circadian lighting effects within the globally-concerned Environmental Building Rating Systems (EBRSs); to advance more steps towards the Green Architecture goals when assessing buildings. Then, it proposed the use of qualitative metrics such as a linked Kano model questionnaire to the EBRSs besides their quantitative metrics; to ensure the proper lighting characteristics and the achievement of the users' desired satisfaction and wellbeing by more accurate and creditable results. Then, case studies were used to prove the importance of using the proposed qualitative metric within the EBRSs.

Keywords: circadian lighting, circadian rhythms, dynamic lighting, environmental building rating systems, green architecture, Kano model, psychological lighting effect.

Introduction

A 'green' building is a building that, during its lifecycle reduces or eliminates negative impacts, and can also create positive effects on the environment. It put a great concern on improving human quality of life, including his physiological sides. The accuracy of the Environmental Building Rating Systems (EBRSs) that were set to assess green buildings is in the focus, especially when taking into consideration the global trend toward proofing the environmental efficiency of buildings before offering them their construction permits (Shamseldin, 2017). The human psychological comfort is one of the important green buildings' functions as set clearly in the Green Architecture principles beside its other important functions, nevertheless, EBRSs included few and static assessment items for the human psychological requirements. A previous research had concluded that users of the Leadership in Energy and Environmental Design (LEED) certified buildings have a similar satisfaction with the users of non-LEED rated buildings, and no considerable effect was found of LEED certification on users satisfaction with the internal environment quality (Altomonte & Schia-

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von, 2013). There are several potentials to include and assess human psychological requirements to raise the quality of buildings. It was proposed in one of the researches to add some assessing items to the EBRSs to assess the users' feel of stimuli, excitation, and belonging to their nature according to their preferences and external circumstances, thus, helping them to constantly recognize the time and orientation in the various internal spaces; by using building elements that can change depending on changeable events and natural features (Shamseldin, 2018).

Light is considered one of the most important environmental human inputs for controlling and organizing human bodily functions. People began spending more time internally after the industrial revolution, thus artificial lighting has a key influence on stabilizing their emotions, mind, and body. Recent researches have studied the influence of lighting color temperature and illuminance variables on mood, motivation, sleep, focus, performance, and concentration, which resulted in the circadian lighting systems' importance to help humans in their actualization through applications (Mott et al., 2012). Different researches have covered the use of the dynamic lighting as a circadian lighting system in different buildings' functions. In the field of office Buildings, economic benefits were concluded when applying the dynamic light technique for the workers' psychological requirements achievement, due to a decrease of absenteeism in the workplace and energy savings compared to the standard lighting systems (Patania et al., 2011). Companies can achieve investment revenues after the replacement of a dynamic lighting system instead of the static one at a medium period, due to the achievement of the workers' psychological requirements and their related working benefits (Gomes & Preto, 2015).

In the field of educational buildings, a considerable dynamic lighting impact on student's oral reading effectiveness was found (Mott et al., 2012). A dynamic lighting system for a smart learning environment to relatively improve students' performance according to the activities rhythms was proposed (Choi & Suk, 2016). Four lighting scenarios of dynamic lighting as a method to form and help learning and teaching activities was also presented (Schledermann et al., 2019). Several other researchers had proposed different other scenarios. In the field of health care buildings, the use of dynamic lighting in their different spaces has an essential role especially for long-duration stays, its use to reduce disease and stress was presented in some researches (Caballero-Arce et al., 2012). The use of light sources and systems that facilitate the implementation of dynamic lighting for various healthcare and medical applications was encouraged (Figueiro, 2013). In the field of industrial buildings, dynamic lighting was proposed to be an integral part of the management process to affect productivity by increasing wellbeing, alertness, production, and quantities, along with absenteeism and process times reduction (Juslén, 2006). A controllable task-lighting system that helps users to select changeable lighting levels leading to a constant significant increase in productivity was examined and recommended (Jusle et al., 2007).

Some quantitative metrics were emerged to measure the circadian lighting effects. A methodology for collecting light-exposure data was developed using three metrics (ACC Care Center – Sacramento, 2019). An application of another three metrics to quantify the effects of natural light on humans has also been presented and recommended, it could be used to build a standard technique to discuss the design choices influence on the accepted circadian framework enhancement achievement (Busatto et al., 2020). On the other hand, using only quantitative metrics to assess a psychological requirement can't be accurate or logically accepted, especially if sensual variables are related to their determination (Ashdown & Eng., 2019). Descriptive qualitative methods such as questionnaires are encouraged rather than the quantitative ones when assessing any of the psychological comfort requirements; due to their subjective characteristics (Shamseldin, 2016b). Using the 'Kano Model' for questionnaires can be uploaded on the network and connected online to the EBRSs assessment; to achieve more creditable, and accurate results when assessing psychological human comfort items (Fekry et al., 2014).

All previous researches were oriented towards the lighting effects and features, but a lack of researches was found to connect them to the assessment of the green buildings, although their obvious effect on human quality of life. This article aims to clarify the circadian lighting application in some different internal working environments and describe the reason to be used to achieve a higher category of green buildings. It proposes the inclusion of the circadian lighting effects in the EBRS versions by assessing them not only using quantitative metrics but also qualitative ones, such as a linked Kano model questionnaire to the related assessment items; to achieve the utmost credible, accurate, reliable, and reasonable assessment results. The research then ends with verification examples using the Kano Model questionnaire to assess the psychological light effect in educational spaces, to clarify its importance to be included in the environmental building assessment.

Methods

The article used analytical methods to shed a light on the effect of light on human psychology, to clarify the need for the circadian lighting effect assessment in the different internal spaces, and to set different examples of the dynamic lighting use in different building types' working environment. The analytical criticism method was used to criticize the current metrics used to assess the circadian lighting performance and to criticize the current inclusion of the circadian lighting performance in the EBRSs. A logical reasoning method was used to propose the Kano Model questionnaire to assess the circadian lighting performance in the EBRSs besides the current quantitative metrics. A practical method was used to measure the illuminance levels for two case studies by the use of a mini light meter. Then a questionnaire that is based on the Kano model was applied to the same case studies to prove the validity of the proposed way to help a more accurate and trusted assessment buildings results, mainly towards the human psychological requirements that should get more concern in the current EBRSs.

Human Psychological Requirements Importance and Status in the EBRSs

Green Architecture is recognized as an efficient consistent system with its surroundings that controls the take and give process with the least negative effects on the human and the environment, and least resources consumption through the building's life cycle. Therefore, forming a healthy community, initializing comfort needs and satisfaction, reducing stress from buildings on their users, increasing satisfaction, and achieving integration with the surrounding environment are some of the Green Architecture principles. The Environmental Building Rating Systems (EBRSs) were issued to assess the building's consistency with the Green Architecture principles. By applying these systems, several assessment certificates were released to confirm the building's commitment to its environment. The Building Research Establishment Environmental Assessment Method (BREEAM) is the first rating system, which appeared in 1990 in the United Kingdom. Many other rating systems appeared from then in different countries. LEED was released in 1998 in the United States and was applied in 2000. It is currently the most famous one, both LEED and BREEAM have their enormous versions and are developing continuously, and other EBRSs around the world benefited and still benefiting from their updates (Altomonte & Schiavon 2013, Shamseldin 2018, Fekry et al. 2014).

Relations in the Green Architecture do not only include the reduction of the external environment's negative impacts on the internal spaces or the reduction of buildings' negative impacts on the external environment but also includes benefiting the nature to improve the building functions, such as the achievement of the users' psychological requirements by sensing the natural changes and their effects on the human emotions and senses (Shamseldin, 2018). Human requirements in Green Architecture are either physical, chemical, radiological, or psychological balances. Human psychological balance is expressed by the users' responses, actions, and behavior, which affects their interaction and performance (Fekry et al. 2014, Shamseldin 2016a).

The lack of human psychological needs results in a mental balance loss and affects his capability of interacting and responding to the environment. Man requires continuous feelings of being connected, interacted, and belonged to nature, and these feelings won't be achieved by constant building aspects. The traditional thought to separate the occupants from their external environment to save them or achieve their physical comfort is against these human requirements. This separation affects people's intelligence and mental status, causes several psychological issues like depression, idleness, and boredom prevents innovation, and creativity, and reduces his ability to activate the imagination. Man needs continual exposure for changes and to live through sequential variations to evolve his thoughts and reserve his intelligence. Developed thinking happens with the variation of emotions and passion. Besides, occupants need the feel of adventure that cannot be achieved unless living or working in a sensual changing environment. In several studies, it was concluded that, if a person stays alone in a constant place for several days, he will experience psychological impacts that appear in different forms, such as anxiety, which level depends on the used light intensity and color. In a conclusion, lighting variations and diversity of views raise the level of satisfaction, on the other hand, the unchanging lighting and constant views will result in sensory stimuli loss and then monotony and boredom (Shamseldin 2018, Fekry et al. 2014).

Although EBRSs' main aim is to assess buildings according to their meet level to the Green Architecture principles, they rarely considered the human psychological needs. The psychological requirements have a weak presence in the EBRSs, especially when compared to the physical requirements. Connecting the occupants visually with their outdoor environment through the openings, besides items associated with providing natural light and ventilation are some of the few related psychological items in the EBRSs, thus the current items don't cover the different human psychological requirements (Shamseldin, 2018). The reason for overlooking these requirements may be due to the lack of their ways of achievement and evaluation. When developing versions or issuing new EBRSs around the world, the main concept and different goals of the Green Architecture should be revised and re-included according to the recent findings and capabilities, and not only updating the already existed assessment items. Therefore, it is essential to search the available current information and encourage more research to include any missing function within the assessment when possible, such as any missing psychological human requirements.

Effect of Light on the Human Psychology

Light affects the human body physically and psychologically. Several studies on psychosomatic showed that both the mind and body affect one another. It is clear that human sensations' effect extends to all our bodies' cells, therefore, controls the body defenses. Thus, appropriate lighting is in charge of the visual function performance, besides the biological and emotional impacts, as shown in Fig. 1 (Figueiro 2013, LİTPA 2019, Gomes & Preto 2015, Schledermann et al. 2019). Besides the rod and cone (photoreceptor) cells that are responsible for normal sight, there are other special cells in the retina known as the intrinsically photosensitive retinal ganglion cells (ipRGCs), which are responsible for regulating several non-visual biological effects including alertness, melatonin production, cortisol production, body temperature, the circadian timing, and heart rate. Fig. 2 shows some of these rhythms. The ipRGCs have their nerve connections, called the Supra-Chiasmatic Nuclei (SCN), which is the biological clock of the brain that sends signals to cells in the body to synchronize their activities (Mott et al., 2012)

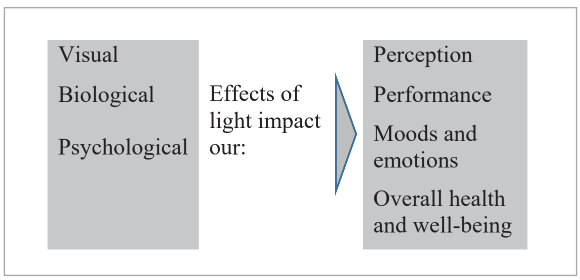

Fig. 1

Interrelations between lighting and its effects (Littlefair & Ticleanu, 2019)

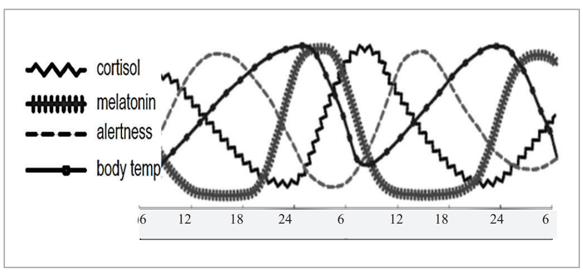

Fig. 2

Double plot (2 x 24 hours) of typical circadian rhythms of body cortisol, melatonin, alertness, and temperature in humans for a natural 24 hour light/dark (Patania et al., 2011)

Man has circadian rhythms that are related to the day's natural light/ dark cycle. Patterns of light and dark present the most significant stimulus that influence the circadian clock to the solar cycle and then helps the waking and sleeping to be at regular times. The circadian clock is then responsible for the release of cortisol ("stress hormone") and melatonin ("sleep hormone") for controlling alertness and sleep. In the morning, the cortisol levels rise and set the human mind and body for the day's coming activity. Simultaneously, the melatonin level decreases and reduces sleepiness. Therefore, the two hormone rhythms are significant for people to function properly when awake, and affect instantly the level of alertness (Busatto et al. 2020, Littlefair & Ticleanu 2019). It should be distinguished between the light role as a therapy and the light and dark role in maintaining healthy people healthy. Depending on the light and dark control, circadian rhythms may be varied, helping the adaptation of people to different night shifts, time zones, or to stop the decline levels of alertness in the afternoon. The control depends on the light exposure timing, then light can delay the clock to a later time or move it to an earlier time (Mott et al. 2012, Littlefair & Ticleanu 2019).

Effect of Artificial Light on the Human Psychology

People spend upwards of 90% of their lives within buildings, yet buildings' internal atmosphere affects their health more than the external environment, while there are many rooms with no direct incidence of daylight. (Gomes & Preto 2015, Kort & Smolders 2010). Usually, the minimum artificial lighting level according to the associated standards is achieved, and no changes in the specified light color temperature or intensity occur during its use after being determined at the beginning, which leads to the exposure to constant monotonous lighting. Both features, illumination intensity, and color temperature are basic artificial lighting system variables. The intensity of light is measured via "Lux" on the work plane to ensure enough illumination for different activities. Correlated Color Temperature (CCT) is measured in Kelvin, which indicates the light hue quality and ranges along the radiation spectrum of light from blue and white (cool) to red and yellow (warm) (Mott et al., 2012). The morning bluish light has an activating effect and stimulates the receptors in the eye to a much greater extent and more melatonin production, on the other hand, the early evening red sky has a restful effect. (Patania et al., 2011). Therefore, light can have a straightforward impact on resetting the circadian rhythm timing by controlling the production of nocturnal melatonin (Caballero-Arce et al. 2012, Blume et al. 2019). Exposure to specific light wavelengths for a long time at a certain intensity affects melatonin production negatively, besides, exposure to artificial light at the wrong times of day can harm circadian rhythms. At night, light can switch the body clock, making the person awake by preventing melatonin production, then sleepier during the day. Alteration of the cycle and the sleep-wake rhythm reversal for night shift workers can lead to biological clock confusion and result in negative health effects.Therefore, artificial lighting is recommended to be guided by the same daylight rhythm when used, or by the space function need of alertness and rest through its occupied time (Copertaro & Bracci 2019, Littlefair & Ticleanu 2019).

The Use of Circadian Lighting in the Working Environment

Circadian lighting is most effective in situations with a low daylight contribution. The circadian lighting idea is the use of electric light that minimizes the negative effect on the human circadian rhythm, with the fact that the visual system needs dynamic patterns (Ashdown & Eng., 2019). The investment of different qualified workplace environments can be recouped by the workers' performance and insurance premiums (Gomes & Preto 2015, Ashdown & Eng. 2019, Caballero-Arce et al. 2012). Dynamic lighting is a lighting system product that applies circadian lighting, it is characterized by dynamics concerning light direction, intensity, brightness, color temperature, and level that attempt to perform dynamism in the internal environments to shore or raise the workers' attention and their sense of well-being. It also refers to the lighting that gives diverse lighting parameters and change over time to enhance user effectiveness to affirmatively influence their energy, relaxation, productivity, visual acuity, and mood (Patania et al. 2011, Gomes & Preto 2015, Choi & Suk 2016, Kort & Smolders 2010). The most important processes are related to the control of the biological clock control over regular light-dark rhythms. To achieve that, cool color temperature and higher illuminance can be applied from the morning to lunchtime, then warmer white light with lower illuminance can be applied during the late morning and afternoon, as shown in Fig. 3 (Gomes & Preto 2015, Kort & Smolders 2010). Other scenarios according to the 'human rhythm' were created for different building functions, as follows.

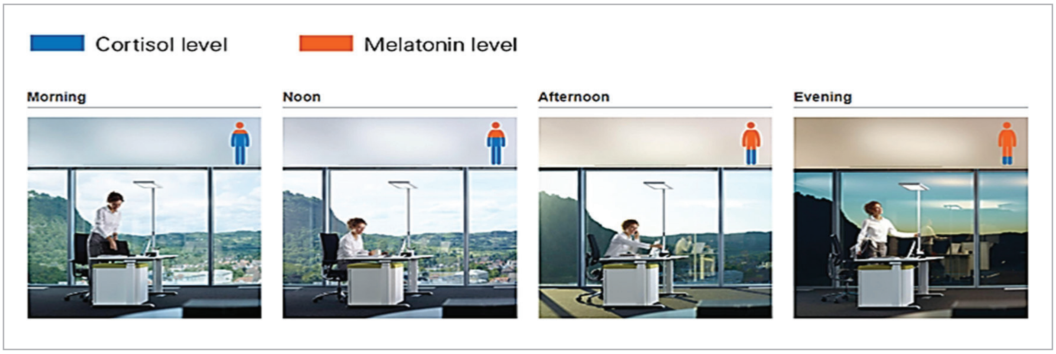

Fig. 3

Controlling biological clock through regular light-dark rhythm. (Waldmann Lighting, 2014)

Office Buildings

In-Office Buildings, mental resources are required for work, attention fatigue and stress are popular office problems (Kort & Smolders, 2010). To reduce the fatigue and stress, many researches on office buildings recommended the following scenario: In the morning, the energy level of people arriving into the office can be increased by a fresh cool light, then at lunchtime, relaxation can be facilitated by the warm light and a decrease of light level, after lunch, as people usually feel sleepy, the light alters to cool white again and its level increases to counter the 'post-lunch dip'. Then, merely before the working day end, a booster of cool-white light is given shortly, without increasing the lighting level, to revive the workers before their home trip, see Fig. 4. Warm white light creates a homely pleasant ambient for people working late. Lighting should be varied gradually, and occupants should have an explanation of what the lighting system is doing and why (Patania et al. 2011, Gomes & Preto 2015, Littlefair & Ticleanu, 2019). For the workers, the advantages of applying the dynamic lighting scenario include high vitality, less anxiety, improved well-being and mood, increased job gratification, improved biological rhythms, and reduced eyes tiredness. For the company, the advantages include fewer error rates, improved task performance and productivity, reduced waste, work-related stress level, and absenteeism, and increased motivation, energy-saving, and job satisfaction (LİTPA, 2019).

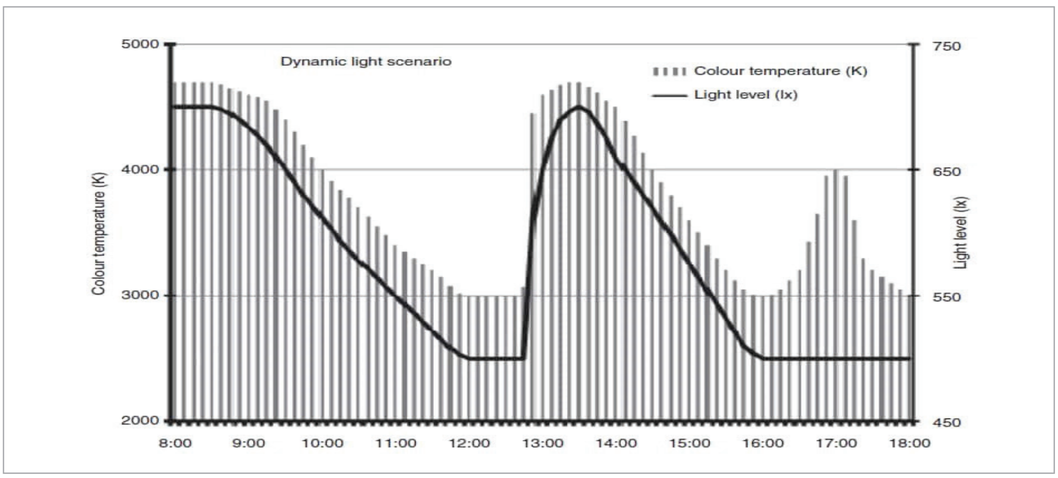

Fig. 4

A proposed dynamic lighting scenario in an office building showing the illuminance and CCT of the lighting plotted against time of day(Kort & Smolders, 2010)

Educational Buildings

In the educational buildings, students spend thousands of hours at school, most of this time is in the classrooms that may exhaust their energies with poor light features (Schledermann et al., 2019). Different researches had proposed different scenarios to be applied in classrooms, but they all shared the concept of giving the teachers the opportunity of changing the light characteristics according to the rhythm of activities, as children need a different stimulating atmosphere in many different learning situations (group work, writing tests, manual work …) to support students' performance and help them concentrate better and learn more easily, especially for classes in the afternoon (Mott et al. 2012, Choi & Suk 2016, LİTPA 2019). Fig. 5 shows one of these scenarios, which consists of the Standard status that was designed to fulfill the normal school standard, the Smart-Board status that was designed to simultaneously stop artificial light weakening contrast of the projected image and allow students to do duties at their desks, the Fresh status that was designed to raise alertness and freshen up the students, besides concentrating attention on the task or the teacher, and the Relax status that was planned to provide an informal and relaxing ambient in the classroom by creating dimmed, warm lighting (Schledermann et al., 2019). Advantages of applying a dynamic lighting scenario for students include improved comfort, increased engagement, attendance, and reading speed, reduced sleepiness, better memory, concentration capabilities, and less anxiety, enhanced social behavior, and decreased errors, hyperactive behavior, and aggression. While advantages for teachers include raised motivation, less work-related stress level, and improved visual acuity (Choi & Suk 2016, Schledermann et al. 2019, LİTPA 2019).

Fig. 5
The illuminance level and CCT of the different luminaire groups were used to create the four lightings pre-sets of a proposed scenario in a classroom (Schledermann et al., 2019)

Health Care Buildings

In the health care buildings, the working environment and motivation hospitals are very intense working environments around 24 hours / 7days, despite that, staff should be capable to efficiently interact and communicate with patients, and others and should be able to make quick decisions under pressure over the time, and focus on urgent duties. In this context, their well-being and stimulus play an important role in the hospital performance and how it is perceived (Caballero-Arce et al., 2012). Dynamic lighting can have a positive effect on patients, especially elderly people, as well as on the staff, who have to be able to concentrate at any time of the day or night. Room ambiances can be varied by lighting to be suitable for various functions, such as creating a bright lighting ambient for an examination purpose or a pleasant, warm lighting ambient when the patient makes a relaxing conversation with guests, Fig. 6 shows two of these statuses. Effective communication of hospital staff

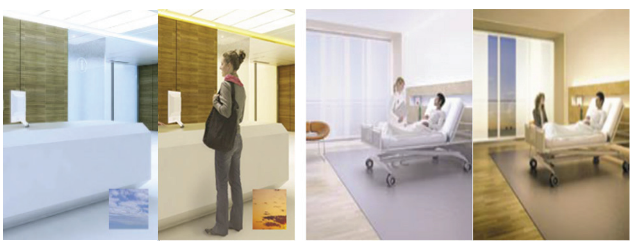

Fig. 6
The use of different atmospheres in hospitals during different times and purposes, at the reception (left) and a patient's room (right) (Philips, 2005)

is in high demand besides the ability to concentrate on urgent duties, especially for surgeons' tasks during operations. Dynamic lighting enables staff to adapt the lighting to suit their own needs. Various researches have concluded that patients retrieved more shortly in day-lit hospital spaces, and that average patient stay and retrieve time can be reduced by optimizing the lighting quality and level (Caballero-Arce et al. 2012, Figueiro 2013, Littlefair & Ticleanu 2019). For patients, advantages of applying dynamic lighting include improved sleep-wake cycles, enhanced well-being and mood, less treatment time, an improved healing process, and biological rhythm, and reduced depression rates. While for staff, advantages include improved work quality, better task performance, lower work-related stress levels, and enhanced visual acuity (ACC Care Center – Sacramento 2019, LİTPA 2019).

Industrial Buildings

In the Industrial buildings, the workers' satisfaction due to their feelings of comfort and safety minimizes the absenteeism rate (ACC Care Center – Sacramento, 2019). A great range of numerous working tasks and interiors is included in the industrial buildings, ranging from soft precision work to heavy industrial tasks, and from large factory halls to small workshops. To ensure adequate visual performance for the related tasks, the quality of light must permanently be high enough, but in a working environment, both action and relaxation are necessary. Dynamic lighting can help to create both conditions, thus, it can help workers to remain alert and to perform better. The use of appropriate shading controls throughout the day and night with alerting blue-rich light together with alternating cycles of shifting dynamic lighting is particularly well suited for industries, as users' alertness is essential through all operation phases around the 24 hours / 7days a year (Gomes & Preto, 2015). Dynamic lighting can provide an invigorating boost that helps to maintain focus and concentration, provide flexible spaces that can be adjusted to the task at hand, and enhance safety and security. **Fig. 7** and **Fig. 8** show some scenarios to enhance workers according to the working environment requirements during different periods. The advantages of applying dynamic lighting for the workers include positive effects on behavior and sleep quality, increased work performance (speed), high work fulfillment, ac-

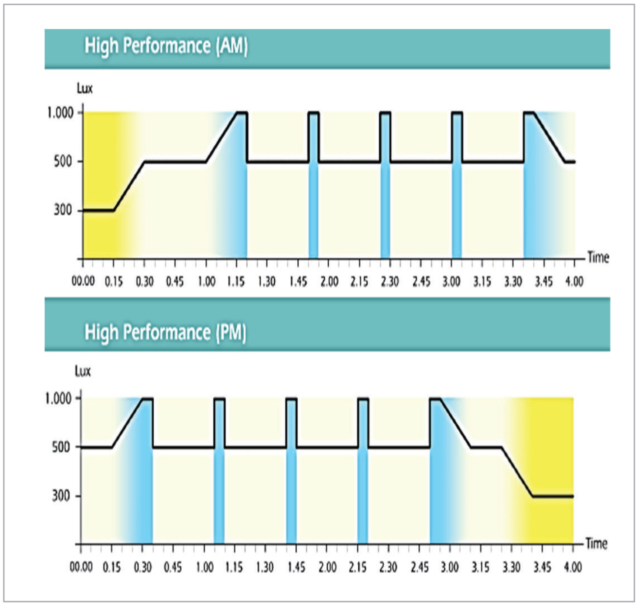

Fig.7

Some dynamic lighting scenarios that help a high working performance for a four-hour working duration, during the day (Top) and night (Below) (LİTPA, 2019)

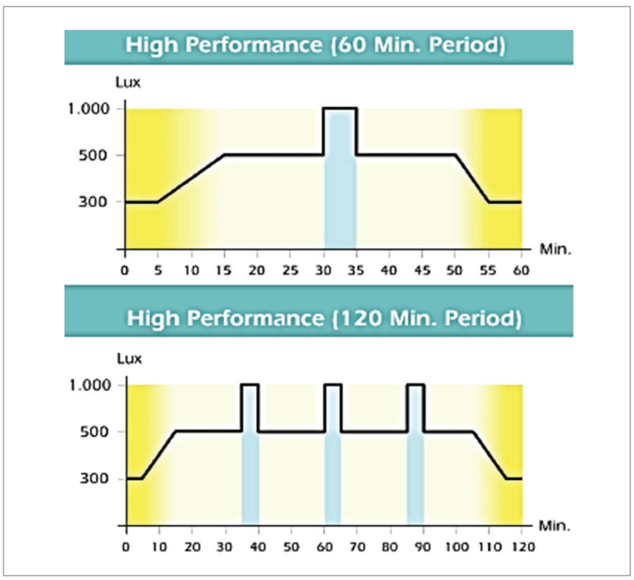

Fig. 8

Dynamic lighting scenarios to help a high performance for an hour (Top), or two hours (Below) working duration (LİTPA, 2019) curacy, and safety, decreased errors, rejects, absenteeism, deregulation, diseases, disorders, and accidents. The total result is improved productivity, besides an increase in the feeling of autonomy, thus, higher job satisfaction (Choi & Suk 2016, Figueiro 2013, Littlefair & Ticleanu 2019) For factories admission, costs of controllable task-lighting could be justified by the positive impact on productivity that is the most significant feature in the industry, yet reducing related health costs (Jusle et al., 2007).

Controlling Circadian Lighting in the Working Environment

Same rooms may be used by numerous users for various functions at varied times. For example, the room that was a working room at the beginning of the day may be used as a presentation room at midday and host a reception at the end of the day. Each of these activities requires different lighting aspects. Dynamic lighting help to chose different ambiances for different activates in the same space over the time (Philips 2005, Krietemeyer et al. 2015). It is important to develop an intelligent, adaptive ambient lighting system, which can analyze and capture the situational and individual variations of the psycho-physiological influence of lighting, then it can also provide the occupants with specific adaptive lighting inputs that are related to their wishes and actual requires, as shown in Fig. 9 (Izsó, 2009). The applicability of adapting the indoor environment into self-preference atmospheres improves users' stimulus and sense of well-being, especially that people of different ages choose different light settings in terms of light intensity and color temperature. Thus, it is preferable to have the ability to modify the light to the users' work, preferences, mood, needs, and physical condition. Personal light allows the user to control the light individually with remote control, while dynamic ambiance changes the light for an entire room automatically according to a programmed (time-based) rhythm. Both scenarios offer different advantages and are designed for different purposes and schemes. This ingenuity helps the circadian lighting to be modified according to the ever-changing working needs and conditions, it is suitable for any place where many different people work together or need to concentrate on difficult tasks. It can also be used to create both significant and subtle atmosphere changes and to give places a special identity. The circadian lighting system can be prepared as an application on mobile, for example, to produce enhanced lighting related to the users' activities. The integrated application allows selecting the most appropriate lighting according to the designed lighting pre-set modes, also, to adjust the illuminance according to the fluctuation of natural daylight (Choi & Suk, 2016). Fig. 10 shows different control systems to perform circadian lighting within a working environment (Mott et al. 2012, Choi & Suk 2016, Littlefair & Ticleanu 2019, Jusle et al. 2007).

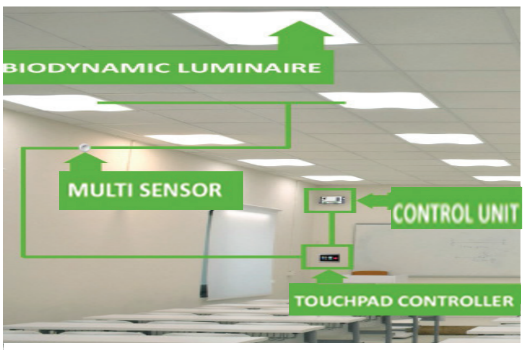

Fig. 9

Lighting management smart control system (LİTPA, 2019)

Fig.10

Two systems to control circadian lighting in a working environment (Choi & Suk, 2016) (Mott et al., 2012)

Current Metrics Used to Assess the Circadian Lighting Performance

To measure the biological effects of light on humans, several quantitative metrics have been developed, such as the Circadian Action Factor (acv), the effective circadian stimulus, melanopic/photopic (M/P) ratios, and the Equivalent Melanopic Lux (EML). The M/P ratio is the melanopic content of the spectrum divided by the photopic content of the spectrum. This ratio is the most widely used, it uses the falling spectral radiation on a surface, and then multiplies it by the response of the ipRGCs to get EML. It is calculated on the eye-level vertical plane of the user, interprets the spectrum of a light source stimulates amount, and is related to the ipRGCs response to light (ACC Care Center – Sacramento 2019, Busatto et al. 2020, Littlefair & Ticleanu 2019, Harry S. Truman Building et al. 2018, Lowry 2018). There are several tools to help to do the calculations of the previous metrics to be easily determined and used, such as the WELL calculator to calculate EML (Ashdown & Eng. 2019, WELL 2019, Konis 2017).

The International WELL Building Institute (IWBI) released the WELL Building Standard to improve health, well-being, and comfort in the buildings and communities' design. It includes illumination guidelines aiming to improve productivity, reduce the bodies' circadian systems confusion, apply suitable visual acuity, and assist better sleep quality. It includes the "Circadian Lighting Design" credit that enhances the production of lighting statuses that assist circadian health to provide users with appropriate light exposure and to create a metric for melanotic vision to enhance circadian rhythms that consider the biological, non-visual light effect beside the visual perception. The standard also provides factors for measuring the EML values for various light colors. When using this way, levels of EML can be determined for various spectra and correlated color temperatures of different light sources (ACC Care Center – Sacramento 2019, Busatto et al. 2020, WELL 2019, Ladopoulos & Shaw 2014). To achieve points for applying this aspect in a project, all regularly used spaces should include lighting that obtains a minimum of specified EML. The WELL standard requirements for work areas as an example are:

- For 75 % or more of workstations, providing a minimum of 200 EML including daylight if exist above the floor by four feet high and simulating the occupant view (facing forward) between 9:00 a.m. and 1:00 p.m. all year round; or
- For all workstations, providing a minimum of 150 EML of maintained illuminance on the vertical plane facing forward.

Similarly, different demands for the learning areas, living environments, and break rooms are set (Ashdown & Eng. 2019, WELL 2019).

Current Inclusion of the Circadian Lighting Performance in the EBRSs

Most current EBRSs include items that are related to artificial and daylighting, but, major lighting-related items and most weighted are about energy conservation. These items include lighting control, daylight integration, and energy savings (Ladopoulos & Shaw, 2014). BREEAM and LEED as the most widespread and well-known EBRSs had the lead to include the circadian lighting concern. Relying on the WELL Building Standard, BREEAM included the assessment of circadian lighting to enhance alertness using bright light during working hours and to switch to lower brightness with warmer color light before it is time to relax. In LEED, one of the main goals of the current Indoor Environmental Quality (EQ) "daylight" credit is to reinforce circadian rhythms, which depends on the measure of daylight illuminance sufficiency for a given area, reporting the percentage of floor area that extends a certain illuminance for a certain percentage of the analysis period. This is checked either by using simulation options to determine the spatial Daylight Autonomy sDA and Annual Sunlight Exposure or to calculate illuminance intensity for sun and sky or by using measurement option for a proper applicable daylit floor area measurement (Littlefair & Ticleanu 2019, Konis 2017, USGBC 2019).

It should be ensured that including the circadian lighting assessment in the EBRSs won't affect other assessment items revenues such as cost, considering that the measurement of the green buildings' cost is always done over its whole life cycle. The inclusion of circadian lighting is likely only if savings in cost and energy and reduction in carbon emissions are coupled with the beneficial effects on human performance, behavior, well-being, and health. Thus, when including circadian lighting in the EBRSs, it is important to cover the limits imposed by current regulations first, and it is important to choose the best energy-efficient lighting alternatives in respect of environmental recognition. Although the cost of installing circadian lighting systems is high compared with the standard system, it can recover economic benefits by the decrease of absenteeism in the workplaces due to the human wellbeing increment and indirectly influenced productivity, and due to the energy savings compared to the standard lighting system (Veitch et al. 2008, Patania et al. 2011, LİTPA 2019).

Proposed Way to Assess Circadian Lighting Performance in the EBRSs

In most situations, lighting in the EBRSs is assessed to achieve the minimum standards according to lighting codes, but, as previously mentioned, EBRSs' new versions should include any newly discovered ways to help achieving a higher level of Green Architecture principles, once there is a capability to do so. And as previously discussed, circadian lighting helps to achieve human psychological requirements that are a part of the overall human requirements related to Green Architecture. Therefore, several assessing items should be added and/or modified to include the circadian lighting applications when needed with proof of achieving its benefits, especially for working environments that are requiring high performance and wellbeing. Accurate results obtained using the EBRSs are considered highly important, but the quantitative metrics can't give the accurate gained benefits of using the circadian lighting, and can't represent the resulted aesthetic and emotional gains of the human being, it can only represent the success of installing its application properly, thus, they can't give certain results for its assessment items (Shamseldin 2018, Gomes & Preto 2015).

Traditional questionnaires usually find the advantages, complaints, defects, problems, and characteristics of a product to achieve particular results. Answers are usually expressing users' satisfaction or dissatisfaction (Fekry et al. 2014, Ingaldi & Ulewicz 2019). Several questionnaires using some indexes and scales have been used in some researches to assess the achievement of better circadian synchronization or entrainment as well as greater subjective and objective alertness. Some were about subjective feelings of stress using the Perceived Stress Scale [PSS-10], sleep habits using the Pittsburgh Sleep Quality Index [PSQI] and Karolinska Sleepiness Scale [KSS], vitality and alertness using the Subjective Vitality Scale [SVS], and depression using the Centre for Epidemiologic Studies Depression Scale [CES-D]. These questionnaires have been used to realize participants' vitality, energy levels in previous studies, and subjective sleepiness. For example, the results for acute alertness measured using the KSS and SVS metrics showed that red light exposure during the post-lunch dip (around 3:00 p.m.) significantly decreased subjective sleepiness, as observed by the lower KSS scores at this time of day. There was also a decrease in KSS scores at noon and departure, but this difference did not reach statistical significance. A similar pattern was observed in the SVS scores (Harry S. Truman Building et al., 2018).

In prior research, it was proposed to use a more accurate, reliable, and credible assessment process to assess the different items linked with sensation and emotions, the proposal depended on the use of the "Kano Model" to apply questionnaires that are linked to the assessment process, and that users are allowed to interact and supply their answers within. This proposal fits this research, as the use of circadian lighting is targeting psychological comfort and need a proper subjective way to express its achievement (Fekry et al., 2014). Therefore, it is proposed to put the Kano questionnaire on a website connected to the EBRS assessment versions, thus the building users are asked to easily access the Kano questionnaire link and express their opinion, which is a fast and simple way to be used in the environmental assessment of buildings. A minimum required number of responses for each building type and area should be determined.

Kano put a process for determining consumer responses to questionnaires as a development of the traditional questionnaire of user's satisfaction. Kano questionnaire uses two questions, one is about the customer's response when achieving an aspect in the product, and the other is about his response when there is a deficiency of this aspect. User satisfaction therefore can be expressed in one of these classifications: indifferent, questionable, one-dimensional, reverse, must-be, attractive. The previous questions can be answered by one of the following choices: dislike – live with – neutral – must be – like. The Kano model diagram is shown in Fig. 11. The two answers are placed on the Kano questionnaire table, the first answer is placed on the vertical side and the second is on the horizontal side, the final outcome is the intersection of the two answers that are: I (indifferent) - Q (questionable) - O (one-dimensional) - R (reverse) - M (must-be) - A (attractive), representing the six user satisfaction categories of the Kano Model, as shown in Table 1. Similar results are collected in one result table, then the ratio of each users' satisfaction (I–Q–O–R–M–A) is calculated (Fekry et al., 2014)(Ingaldi & Ulewicz, 2019)(Wu et al., 2015).

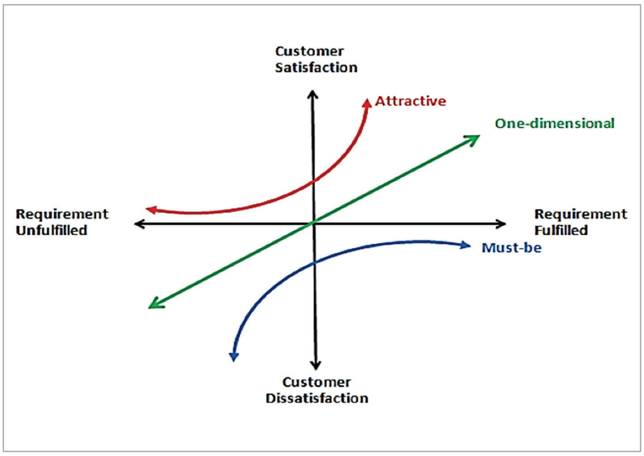

Fig. 11

Kano model diagram (Ingaldi & Ulewicz, 2019)

Table 1

The Kano evaluation table with an example of determining the ratio of user satisfaction (Ingaldi & Ulewicz, 2019)

Customer requirements		Dysfunctional (negative) question: reaction without the feature				
		Like	Must be	Neutral	Live with	Dislike
Functional (positive) question: reaction with the feature	Like	Q	A	A	A	O
	Must be	R	I	I	I	M
	Neutral	R	I	I	I	M
	Live with	R	I	I	I	M
	Dislike	R	R	R	R	Q

The customer satisfaction coefficient (CS) should be then measured. It is calculated using two formulas, the first is $(A + O) / (A+ O + M + I)$ with a positive signal, and the second is $(O + M) / (A +O +M + I)$ with a negative signal, then the two positive and negative results are gathered in one result. This result is the assessment of the products' characteristics. The closer the value to (-1), means that it leads to the user's dissatisfaction, the closer to (+1) the preferable the product is, however, it is ineffective if the value is 0 (Fekry et al., 2014) (Wu et al., 2015)(Ingaldi & Ulewicz, 2019). By collecting users' opinions, the CSs are measured, then they are collected to have a final output from (-1) to (+1), taking into account that numbers from zero to (-1) maybe count as zero in the EBRSs. Then, the result is multiplied by the item's weight that expresses its importance, which is previously determined by the EBRSs makers. That means, that the item's score is calculated by multiplying the CS result by the item's maximum score to get the item's final grade (Fekry et al., 2014).

Circadian lighting items results could rely on quantitative results when submitted to the assessors with the building design documents using the simulation options, then assessors may assess the items' intent verification during the operational phase of the building through specified periods depending on the questionnaire. Thus, these items could be considered from the group of items that need a time that exceed the construction phase to be assessed. The first occupation year may be determined to finish the building assessment regarding these items and to ensure achieving the desired requirements, which request initial permits to operate the building based on initiatory environmental results, then they are developed and updated according to ongoing assessors' reviews. Thus, experts should specify the periods required to repeat this questionnaire to ensure the continuity of achieving the item's results. The questionnaire can be collected in online survey software, and there are also dedicated online tools specialized in the Kano model and its analysis that could be used.

There are several benefits when linking the assessment items that are related to the circadian lighting use by the Kano questionnaire. Besides dealing with the users' subjective properties to get more credible, reliable, and accurate assessment results than the quantitative assessment results, it provides helpful information on the requirements that should be accomplished to improve users' satisfaction, helps to minimize the needed time and effort of the assessment, and helps to ensure the continuity of the achieved results when repeating the questionnaire through different predetermined periods (Fekry et al., 2014).

Variables affecting the production of EBRS versions and the assessment of buildings are the spatial (natural and human), temporal, and building types variables (Shamseldin, 2017). When including quantitative metrics among the different EBRS issued versions, it should be noted that these variables should have a role in changing the assessment values over time, place, and building types, such as the inclusion of the circadian lighting quantitively. Spatial variables, for example, affect the people's CCT preferences along with the differences in weather and temperature conditions, as in Europe, there are differences between the colors temperature preferences among its regions. While in northern Europe more warmer color temperature lamps are sold, in the south more cooler color temperature lamps are sold, whereas in areas with considerable daylight, the artificial lighting color temperature is not so apparent if the spaces were good day-lit (Juslén, 2006). For temporal variables, the different technologies and findings should be included contentiously to ensure achieving the utmost environmental benefits over the time. The types of building variables are related to the different scenarios according to each building types' characteristics and users' needs as previously explained (Busatto et al., 2020). On the other hand, the use of Kano model to assess the circadian lighting effect can be used for all EBRS versions without changing the related items for a different time, place, and building types variables, thus save a lot of time and effort on the contrary of dealing with the quantitative metrics assessment items options.

Case Studies for Using the Kano Model in Assessing the Effect of Light on Circadian Rhythms

Two drawing halls at the faculty of engineering, Ain Shams University, Cairo, Egypt, are typically designed except for their vertical windows' orientation. Hall (A) has its widows oriented towards the North as in Fig. 12, while hall (B) has its windows oriented towards the South as in Fig. 13. Both halls have a daylight contribution in their overall lighting, either through skylights or through the vertical striped windows. Although these windows are of a little lighting intensity level contribution, they have a notable effect on the lighting color temperature, especially when switching the artificial light off. The students using these halls stay for a long time drawing and studying, thus keeping their alertness at a high level is very important. Two lecture rooms at the faculty of engineering, Taif University at Taif city, Saudi Arabia are typically designed except for their windows' orientation. Lecture room (A) has its widow oriented towards the North as in Fig. 14, while

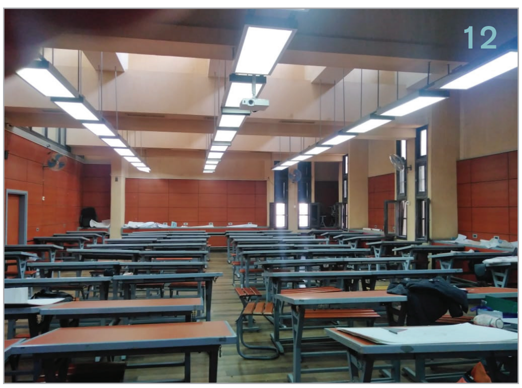

Fig. 12

Drawing hall (A)

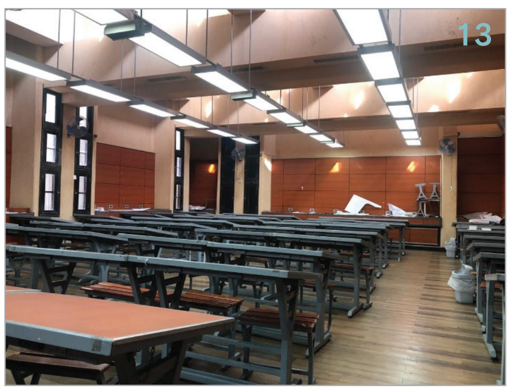

Fig.13

Drawing hall (B)

Fig. 14

Lecture room (A)

Fig.15

Lecture room (B)

Lecture room (B) has its window oriented towards the South as in Fig. 15. Both lecture rooms rely on the different oriented windows to achieve their natural light. The students using these lecture rooms may stay for a long time of the day to attend different lectures, starting 8:00 am and ending at 4:00 pm, thus keeping their alertness at a high level is also very important.

Results

By using a mini light meter on a 3-meter square grid, both drawing halls were found to have approximate illuminance levels on their work plane height during hours between 9 a.m. and 3 p.m. with the artificial lights turned off to be between 300 and 700 lux in March and November 2019 respectively on a 75% of their floor area. And both lecture rooms were found also to have approximate illuminance levels on their work plane height during hours between 9 a.m. and 3 p.m. with the artificial lights turned off that are between 300 and 500 lux in May and September 2020 respectively on 75% of their floor area. The selected months were chosen according to the measurement option in the LEED “Daylight” assessment item’s optional months.

For four days in 2019, the same students used the two halls, two days in each hall, once with the allowance of windows contribution in lighting the halls, and once after blocking them and using the artificial light to cover the loss of the natural illuminance level intensity beside the help of the skylights. And for four days in 2020 same students used the two lecture rooms, two days in each lecture room, once with the allowance of the windows contribution, and once after blocking them and depending only on a sufficient artificial illuminance level intensity in lighting the lecture rooms. A Kano model questionnaire was used to assess the students’ alertness satisfaction in the two halls and two lecture rooms. The questions were:

- Discuss your alertness level without blocking the windows’ natural light during these times: 9 a.m., 12 a.m., and 2 p.m.
- Discuss your alertness level when blocking the windows’ natural light during these times: 9 a.m., 12 a.m., and 2 p.m.

The Kano evaluation table was then used for the students’ answers to get their satisfaction categories results regarding the presence of the daylight during the studying period, noting that the main effect of its presence is its color temperature feature, as the light intensity was already sufficient for all four spaces with the contribution of the window or after blocking them. Table 2 and Fig. 16 show these results.

The total customer satisfaction coefficient (CS) was calculated for the previous four spaces using the mentioned formulas in the previous section, noting that numbers from zero to (-1) if existed will be considered zero as previously proposed.

Total CS for drawing hall (A) = 0.6 - 0.55 = 0.05, for drawing hall (B) = 0.7 – 0.38 = 0.32, for lecture room (A) = 0.68 – 0.74 = - 0.06 (will be considered 0), for lecture room (B) = 0.76 – 0.4 = 0.36

Table 2

Collected satisfaction categories of the Kano model questionnaire for the case studies regarding the contribution of the daylight color temperature feature on the students' alertness

Satisfaction category	Number of students			
	Drawing hall (A)	Drawing hall (B)	Lecture room (A)	Lecture room (B)
A (attractive)	16	22	2	12
M (must-be)	14	10	3	3
R (reverse)	6	10	7	4
O (one-dimensional)	8	4	11	7
Q (questionable)	2	1	6	3
I (indifferent)	2	1	3	3

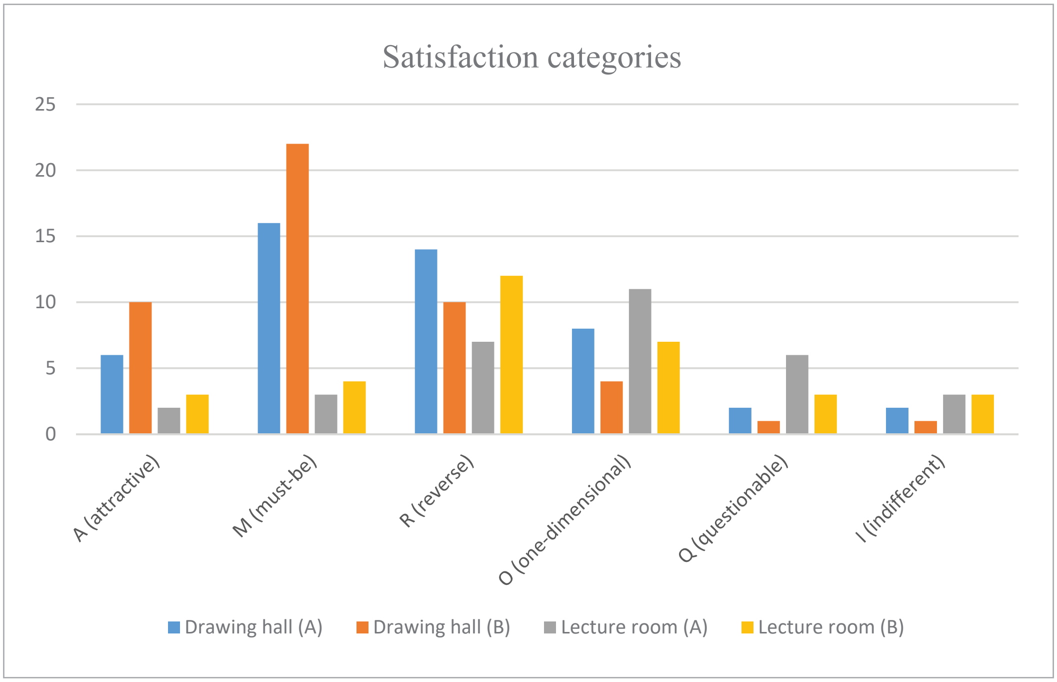

Fig. 16

The case studies users' satisfaction categories regarding the contribution of daylight on the students' alertness.

These results are then multiplied by the item's weight as previously proposed, which is "Daylight" in LEED for example. This item's weight is 2 to 3 points for newly constructed schools according to the measurement option at its operational period, 2 points when achieving illuminance levels between 300 lux and 3,000 lux for the floor area at an appropriate work plane height during any hour between 9 a.m. and 3 p.m. for 75% of the regularly occupied floor area in specified corresponding months as already chosen in the two case studies and determined in the LEED scheme.

Thus, without the inclusion of the Kano model results, all previous spaces will achieve 2 points score according to the quantitative measurements, but according to the proposed method of including Kano model results, the item's score for each previous space is as follows.

Item score for drawing hall (A) = 0.1, item score for drawing hall (B) = 0.64, item score for lecture room (A) = 0, item score for lecture room (B) = 0.72

Discussion

If one of the EBRSs that included the circadian rhythm assessment such as LEED is used to assess the achievement of the circadian rhythms in the previous four spaces to discuss its current assessment results credibility, the discussion is as follows. The item: "Daylight" is the current existed item in LEED for that purpose, which leads to the achievement of 1 to 3 points for schools according to their achievement levels. All options used to assess this item rely on quantitative tools, such as the use of simulation or measurement results to decide the points achieved. The measurement option requires the achievement of illuminance levels between 300 lux and 3,000 lux for the floor area. Thus, according to the measured illuminance levels, both drawing halls and both lecture rooms have to achieve the same assessment points in LEED, while when the two halls, and the two lecture rooms were used by the same students at the same time of the day in the same week and month, their reaction on the effect of light on their alertness varied between them. Which means that, although these spaces will get the same score points for their natural light effect on the psychological need when assessing the circadian rhythms achievement item in LEED, there were different psychological reactions among the students who used them, which gave different qualitative results (USGBC, 2019).

The different results between the similar but different oriented spaces may be due to the difference of some light characteristics between the southern and the northern directions that are not included in the light intensity feature, such as the diversity of the color temperature. These results emphasize the importance of including the psychological lighting effects side to side with the physical requirements because if depending only on the physical comfort needs, the educational spaces with the northern windows would often be preferred to avoid glare and overheating in summer than the other directions, without concerning the psychological effect, while including both physical and psychological needs will lead to achieving all of them in an equal or relative concern with the proper treatments. These results also prove the importance of including quantitative results besides the qualitative ones when assessing psychological human requirements in the EBRSs.

The general low effect of the daylight color temperature on the students' alertness when depending only on the windows to provide the dynamic color temperature within the time of the spaces' occupation is notable. This may be due to the weak ability of the windows to provide dynamic lighting characteristics from only one side of the space. The windows cannot give all the students the same and adequate sense of dynamism, and cannot simulate the outdoor light characteristics. Even for the halls that have skylights, the entered light was indirect and couldn't give the expected light dynamism. On the other hand, the current assessment items in the EBRSs that included the circadian light assessment relied only on the natural light to reinforce the circadian rhythms. The inclusion of artificial dynamic light to achieve the required benefits of a dynamic color temperature according to the building functions and performed activities in the EBRSs is then a good field to be studied and focused on. It is expected to achieve much more users' satisfaction and psychological requirements by using dynamic artificial lighting with or without the help of natural light. As it can create a homogeneous light color temperature for all users, can be controlled, and have wide base studies of the recommended relations of the building functions and the users preferable lighting scenarios, besides the more studies that could be done in that direction. The use of the Kano model questionnaire could then help the verification of the different light characteristics' effect on the users' psychological requirements and help the decision of the light choice in the future.

It should be noted that the reliance on dynamic artificial lighting to achieve the psychological effect of the daylight color temperature helps the ignorance of the orientation effect on that feature, and gives the chance of directing the windows according to the other building environmental functions.

Conclusions

The Environmental Building Rating Systems (EBRSs) were set to ensure the achievement of Green Architecture goals, thus they should safeguard the users from emerging poor and unhealthy work environments, especially when knowing that the ignorance of the psychological requirements leads to mental and physical effects. Thus, applying circadian lighting to achieve building users' wellbeing and satisfaction in the working environments is a very important issue that should be considered in the building assessment with proper accuracy.

To include the circadian lighting effect into the EBRSs, there should be a proper way to be assessed and ensure the achievement of its benefits and gains. Several quantitative metrics were presented recently to measure the circadian lighting effect. But the use of quantitative metrics to deal with the descriptive and subjective characteristics may lead to uncertainty, as psychological requirements can only be ensured using subjective results such as those resulting from questionnaires. Kano Model questionnaire is proposed as an easy and accurate way to summarize the users' satisfaction of using circadian lighting. It can be linked by the assessment systems using appropriate links. Using a linked Kano questionnaire gives several advantages such as achieving accurate and credible results for the circadian rhythm assessment, ensuring the continuity of achievement, minimizing time and effort of assessment, and helping the ease of the assessment inclusion in the different EBRSs versions despite the spatial, temporal and building types affecting variables.

It is recommended to include the circadian lighting assessment in the EBRSs versions that is one of the human requirements that still not existed or well-included in the current EBRSs. It is recommended to do more researches on the way of using circadian lighting and its applications to enhance the users' circadian rhythms among different conditions and working environments. And recommended using the circadian artificial light applications in the assessment options of the circadian items in the EBRSs rather than depending only on the natural light effect that often cannot give an equal color temperature effect on all users, and cannot be controlled. Designers of green buildings are recommended to connect the users of the buildings with their external environment or simulating its dynamism within the internal spaces to achieve better psychological influences. They are also recommended to study every building function's need of circadian rhythm to apply it according to their best scenarios. It is recommended to give the users the ability to control or adapt their internal lighting features over time, different purposes, and personal preferences while changing the overall circadian lighting application automatically according to a programmed rhythm.

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