


Review

Towards a Sustainable Indoor Lighting Design: Effects of Artificial Light on the Emotional State of Adolescents in the Classroom

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Abstract: In recent years, articles have been published on the non-visual effects of light, specifically the light emitted by the new luminaires with light emitting diodes (LEDs) and by the screens of televisions, computer equipment, and mobile phones. Professionals from the world of optometry have raised the possibility that the blue part of the visible light from sources that emit artificial light could have pernicious effects on the retina. The aim of this work is to analyze the articles published on this subject, and to use existing information to elucidate the spectral composition and irradiance of new LED luminaires for use in the home and in public spaces such as educational centers, as well as considering the consequences of the light emitted by laptops for teenagers. The results of this research show that the amount of blue light emitted by electronic equipment is lower than that emitted by modern luminaires and thousands of times less than solar irradiance. On the other hand, the latest research warns that these small amounts of light received at night can have pernicious non-visual effects on adolescents. The creation of new LED luminaires for interior lighting, including in educational centers, where the intensity of blue light can be increased without any specific legislation for its control, makes regulatory developments imperative due to the possible repercussions on adolescents with unknown and unpredictable consequences.

Keywords: natural lighting; visual comfort; artificial lighting; indoor lighting design; chronodisruption; circadian rhythms; daylighting; sustainable lighting design; LED luminaires; indoor environment quality; classroom lighting

1. Introduction

In recent years, an unprecedented technological revolution has taken place. Many of the luminaires that humans use are being replaced by new light emitting diode (LED) light sources. Unlike the luminaires that have been used until now, which had fixed and known emission spectra, the spectral composition and intensity in each range of the visible spectrum of these new LED luminaires can be made to order, even including fixed or remote electronic control systems, and can be varied as desired at any time.

It is a scientific fact that human beings have genetically evolved to perform their activities during the day and rest during the night. The evolution of the human species has occurred under periodic and relatively stable cycles of light and darkness, next to the main cycle, which is linked to the rotation of the Earth on its own axis (light–dark cycle, 24 h) and the rotation of the earth around the sun

(seasons, changed daylengths as a function of latitude, annual cycle, lunar cycle). Natural selection has favored the presence of biological clocks through all lines of evolution, allowing animals to optimally benefit from these cycles [1–4].

Maintaining proper lighting cycles, with appropriate levels of light during the day and darkness at night is beneficial to the synchronization of the circadian system. It is not only the amount or type of light we are exposed to that is important, but also the time of day when that light is received. Biological rhythms persist in constant environments; the origin of such rhythms is endogenous and depends on an internal clock. They are not, by default, driven by external signals but do have the ability to become driven by several of these signals.

The increasing use of electronic equipment late at night from an early age has aroused curiosity and fear about various related consequences, especially for children and adolescents [5]. Therefore, in this review, we examine all relevant scientific and regulatory information that exists or is under development. Numerous scientific studies demonstrate the influence of light on our biorhythms, and therefore, on the moods of adolescents [6,7].

The evolution in lighting with the introduction of LED lights that can emit any wavelength at any intensity has raised concerns about what combinations of light can be received and emitted by electronic equipment and disturbing doubts about such light's consequences for the health of adolescents.

The main objective of this review is to study the different sources of artificial light that adolescents may receive and the physiological and psychological consequences of their absorption. From this general objective, the following specific objectives were developed:

- a. determine the nature of the light emitted from electronic equipment that can be used by adolescents from the perspective of the possible risks of blue light on the retina and its effects on circadian cycles and mood,
- b. evaluate the new sources of indoor lighting that can be installed in educational establishments today and their possible influence on mood,
- c. study the current regulations (or those under development) related to new sources of artificial light, and
- d. propose control or preventive measures to improve the health of adolescents.

The light used in the personal and educational contexts of adolescents can be harmful, so there must be an awareness of the need to implement ethical and healthy regulations related to lighting to optimize the health and performance of young people in school contexts [1,3]. It is essential to carry out a bibliographic review and a review of the current regulations in all proposed areas to successfully legislate and set limits on the emissions of new LED lights according to their uses.

Research and practice in the domain of indoor lighting design have become a relevant topic in the search for indoor environment quality. A keyword search of articles and abstracts related to these research areas was carried out through the Web of Science (Figure 1). Indoor lighting design was the keyword.



Figure 1. Keywords for indoor-lighting-design-related issues.

2. Methodology and Sources of Information

The aim is to study certain processes that occur in nature without intervening or manipulating the possible variables. For this purpose, an analysis of the physiological and psychological consequences of the absorption of light through the human visual system will be carried out through an exhaustive bibliographic and documentary review based on the proposed objectives. In this review, we undertake a study of the existing literature in the scientific community concerning the effect that artificial lighting can have on adolescents, including an exhaustive study of the literature on lighting in classrooms, the use of natural lighting, quality requirements of the interior environment in classrooms, and how lighting influences the visual health of adolescents.

The Federation of National Manufacturers Association for Luminaires and Electrotechnical Components in the European Union (CELMA) published measurements of several LED luminaires with an illuminance of 500 lx showed that none of these luminaires had blue emissions in group 2. EN 62471 classifies light sources into four risk groups: 0, 1, 2, and 3 (where 0 = no risk and 3 = high risk). The sun is classified as high risk, or group 3 [8]. Further measurements by the French Agency for Food, Environment and Health and Safety at Work (ANSES) in 2010 showed that all measured LED sources were in groups 0 and 1 according to EN 62471 UNE EN 62471:2009, the “Photobiological safety of lamps and appliances using lamps”. This risk is measured according to two different methods, depending on the product being measured [8].

La EN 12464-1, the European standard for indoor lighting, has detailed the recommended values of illuminance and uniformity for classrooms (6.2 Educational Buildings) with light levels between 300 lx, and 500 lx (EN 12464-1, 2002) [9]. Figure 2 shows the blue light retinal exposure risk weighted irradiance for small sources (E_B).

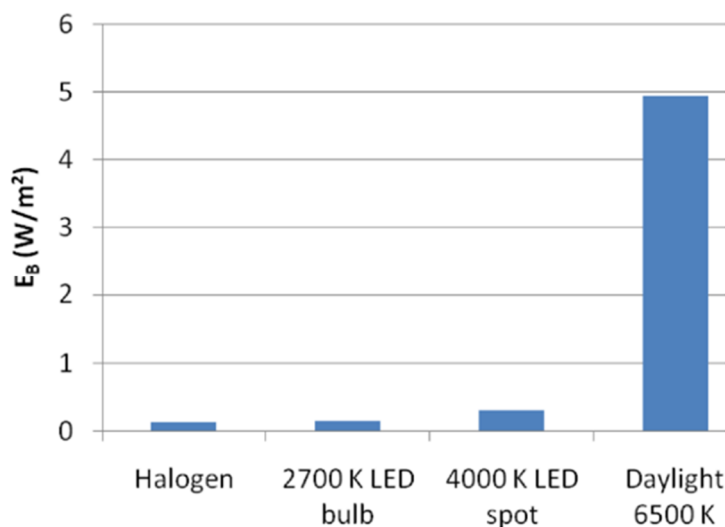


Figure 2. Comparison of the irradiance values of some lamp types at 500 lx (typical for indoor lighting) with daylight at 5000 lx (typical for outdoor lighting) [10].

Light emitting diodes (LEDs) are light sources in which light is created within solid-state materials. The light emission is obtained by the interaction of an electric field with the solid material. The physical process is called “electroluminescence”. This phenomenon was discovered as early as 1907, and the first practical product based on it was created in 1962. The semiconductor material used in LEDs is selected so that it emits in the visible or ultraviolet range. Different materials produce light with different wavelengths (different colors). They have the characteristic of having a very narrow range of emissions.

The general lighting levels used in interiors via LED luminaires with cold color temperatures of 4000 K, 6500 K, and even 9000 K (whose blue components very high) are never enough to cause damage

to the retina, as long as one does not look at the naked light source. The possible photobiological risk of blue light can be assessed using the criteria set out in EN 62471 [10], which have been indicated above.

From three billion years ago until 130 years ago, living organisms had one part of the day of sunlight, and other part of the day, darkness. From 130 years ago until today, thanks to artificial light, humans have experienced short periods of sleep, dim light inside the buildings where we work, short periods of time receiving natural light, bright light in the bathroom during the night, and dim light in the bedroom while we sleep [11,12].

Before the invention of electric light, humans had a “first sleep”, after which they would arise and engage in tasks or go and visit neighbors. Then, they would have a “second sleep”. This whole process took about 12 h. Today, we have only one sleep that lasts 7 or 8 h at most [13,14].

The study of the non-visual effects of light entering our eyes is so topical that the 2017 Nobel Prize in Physiology and Medicine was awarded jointly to Jeffrey C. Hall, Michael Rosbash, and Michael W. Young [15] for their discoveries on the molecular mechanisms of circadian rhythm control. Below are some terms that have emerged in this new branch of science.

Chronobiology is the branch of science that deals with the physiological variations of living beings called circadian rhythms, which occur approximately every 24 h, as well as the study of the processes of synchronization with the surrounding environment. The variation of endogenous circadian rhythms that are determined from individual differences and psychological factors is described as a chronotype. Twenty-five percent of people are active from noon onwards, go to bed late, and then get up late; these people are commonly called “owls” [11].

Smolensky and colleagues define chronodisruption as an alteration in the internal temporal order of physiological, biological, and behavioral rhythms. If chronodisruption becomes chronic, the asynchrony, advancement, or retardation of peripheral clocks may occur [16].

3. Possible Effects of Artificial Light Absorption on Adolescents

3.1. Studies on the Non-Visual Effects of Light Absorption through Our Visual System

Stevens and Zhu [17] observed that the sun is our primary source of light during the day and that for millions of years sunlight has shaped mammals’ endogenous circadian rhythms including when to wake up, body temperature, metabolism, oscillations of gene expression, and hormone production throughout our bodies. Electric light, in contrast, is dim and alters all aspects of our internal circadian rhythms. Its intensity and spectral content are often not adequate during the day for proper circadian resetting and are too great at night for “true darkness” to be detected.

In 1975, the scientist Richard J. Wurtman wrote an extensive article talking about the effects of light on our internal organs, such as the ovaries, and tissues, such as the breasts. This publication was visionary because of the knowledge of the scientific community at that time [18].

Guido et al. [19] established that the retina contains a biological pacemaker that influences the entire circadian system. Glickman et al. [20] stated that an illuminance of 2500 lx is necessary to suppress nocturnal melatonin in humans, but it was later determined that under certain conditions, such as below 1 lx, melatonin can be suppressed in humans.

There is a growing trend in the scientific field to a consensus that exposure to light influences many psychological processes through at least two pathways unrelated to the phenomenon of vision [21]. The best-known pathway is related to the regulation of melatonin secretions by the pineal gland [22]. This pathway controls circadian rhythms. Exposure to light at night, particularly at short wavelengths, suppresses melatonin and influences insomnia. The other pathway acts on the level of alertness by activating a mechanism separate from that of melatonin suppression, during which cortisol is secreted [21].

Given the large amount of data that is gradually appearing on the positive and negative effects of artificial light related to health, Erren et al. defined photohygiene as exposure to light under the optimal conditions of periodicity, quality, and quantity [23].

A study carried out by Cho et al. [24] stated that sleeping with the lights on causes acute negative effects on the structure and quality of sleep. A later study showed that these negative effects could affect aspects related to memory by producing corneal levels of less than 10 lx. The experiment was conducted with a 5779 K LED source with a diffuser [25].

The World Health Organization's (WHO's) International Agency for Research on Cancer (IARC) has classified "shift work involving circadian disruption" as probably carcinogenic to humans (group 2a). Continuous light contributes to acute confusional syndrome in adult intensive care units, where environmental constancy is the norm [26].

Dim light melatonin onset (DLMO) refers to the onset of melatonin secretion under low light conditions. The human body is programmed for this moment to occur when the sun is setting. Graham and Wong [27,28] noted in their study that intense blue light cancels the night peak 10–20 min after exposure, which returns to its initial value after 40 min once the stimulus is removed.

In relation to the time of day, exposure to light can generate clock advances or delays as defined by the phase response curve (PRC), so bright light at the beginning of the biological night (from the start of melatonin elevation to the time when the minimum body temperature is produced) generates a phase delay, while in the morning (from the minimum body temperature to 8 h later), it produces an advance. Epidemiological, clinical, and experimental studies with animal models show that the chronodisruption produced by artificial light during the night may be related to pathologies such as the increased incidence of metabolic syndrome [29], cardiovascular disease [29], and cognitive and affective disorders [30].

Exposure to light at night (LAN), reduced or inadequate light intensity during the day, or decreased contrast in the light–dark cycle all contribute to chronodisruption (CD). The cognitive decline, affectivity, behavioral and sleep disturbances, and limitations in the daily activities of elderly patients with senile dementia and their caregivers have been associated with alterations in circadian cycles [31]. Artificial light at night (ALAN) is drawing the attention of researchers and environmentalists for its ever-increasing evidence on its capacity for "desynchronization" of organismal physiology [32]. Obesity is a common disorder with many complications. Although chronodisruption plays a role in obesity, few epidemiological studies have investigated the association between artificial light at night (ALAN) and obesity. Since sleep health is related to both obesity and ALAN, Koo et al. [33] investigated the association between outdoor ALAN and obesity after adjusting for sleep health and the association between outdoor ALAN and sleep health.

Simón and Sánchez [34] noted that about 20% of people in today's society spend most of their time during the day indoors under dim lighting, with low physical activity and irregular, short sleep cycles. The authors suggest that these factors could contribute to the prevalence of chronodisruption possibly facilitating pathologies such as cancer, intestinal conditions, metabolic syndrome, cardiovascular diseases, mood disorder, and cognitive impairment. Chronodisruption may also adversely affect melatonin and cortisol levels. Cortisol is a regulator of stress-related functions [34]. In 1998, Sterling and Eyer [35] defined the role of allostasis as "maintaining stability through change" and noted that cortisol secretion and stress are a "body's adaptation to an unknown situation that must be transient and therefore blocked or stopped". The authors comment that night shift workers have a high risk of circadian disruption and, therefore, hormonal alterations. Similarly, Mirick et al. [36] suggest that a low level of urinary sulfatoximelatonin is related to working at night, which results in higher levels of cortisol.

Stevens and Zhu [17] state that light is a regulator of psychology and behavior and that its effects have evolved over millennia throughout which illumination has provided reliable information about the time of day. The authors claim that the advent of electric light has now altered this relationship with patterns of light exposure reflecting personal tastes and social pressures. It is important, therefore, that non-visual light effects be incorporated into lighting design. For example, one might ask to what extent existing architectural lighting replicates the biological effects of natural light, how lighting could be used to minimize the harmful effects of shift work while promoting alertness and safety, or how

light therapy could be optimized. The lighting industry and scientists have begun research in this direction. They argue that we must first determine how light impacts human behavior and psychology. There are two different techniques for measuring light and there are different scientific criteria to determine which of the two is the most suitable: radiometry (quantitative analysis) and photometry (qualitative analysis).

Several studies have observed that humans are adopting increasingly nocturnal lifestyles, both for work and for leisure, which has resulted in the night becoming excessively illuminated, while we spend most of the day in poorly lit interiors. This results in an increasing gap between our habits and the natural synchronizers of the circadian system. Chronodisruption or circadian disruption (CD) is the physiological price of exposure to light at night [16,17].

It is well established that light affects both visual and non-visual systems. Little attention has been given to testing the effects of light on building occupants' non-visual responses, and, consequently, lighting specifiers have been offered little guidance on the design and application of lighting for non-visual effects. A study conducted by the Lighting Research Center, by Figueiro et al. (2019) [37], helped to fill that gap through field-testing of light exposures from a novel luminaire designed to promote entrainment and alertness throughout the day in actual office environments. The data supported the inference that light exposures, when properly applied, can promote circadian entrainment and increase alertness.

Recent research has shown that exposure to bright white or high blue light stimulates alertness, but these effects are not seen in tasks that demand a high cognitive level. Individual and psychological differences have been taken into account to explain the variability in the cognitive effects of light. Sensitivity to light depends on individual differences in the PER3 gene clock involved in sleep–wake regulation, age, the cognitive domain, and task difficulty [38]. Some authors claim that exposure to bright daylight indoors can result in positive vitality, alertness, and help promote a healthy, active day. These studies reveal that bright light induces improvements in alertness when healthy participants are experimentally deprived of sleep or light prior to exposure to this indoor light [39].

Experimental studies have shown that the magnitude and duration of non-visual light effects depend on previous light doses [40]. Exposure to bright indoor light would induce weaker non-visual effects in spring than in autumn and winter [39].

Angel Correa et al. [38] observed that bright white light or light enriched in the range of blue increases alertness but that this is not effective for high cognitive level tasks, such as sustained attention to task response (SART). The authors observed that the results varied greatly depending on the individuals and their previous states of alertness, with higher results among those who previously had a better state of alertness or vigilance.

Wright Jr. et al. [41] conducted an experiment in which they recruited eight participants (two women and six men) aged around 30 years old whose circadian cycles were previously studied at their work and home. The participants then spent a week camping in the mountains without electricity. Among the eight subjects, there was a wide range of chronotypes (i.e., larks and owls) and sleep times. The beginning of melatonin release is approximately 2 h after sunset. Due to the habits of modern life, this release now occurs later. After a week of camping, the beginning of melatonin secretion occurred closer to sunset and elimination occurred at dawn, aligning larks and owls more closely to the duration of natural light. In their conclusions they state that “increased exposure to sunlight may help reduce the health consequences of circadian disruption”.

3.2. Analysis of the Possible Negative Effects of Blue Light from Electronic Devices on the Eyes of Adolescents

The first type of cancer to be associated with the suppression of melatonin production was breast cancer in a 1987 publication by Stevens [42]. Stevens claims that the level of ambient light in the room during the sleep period is associated with other diseases such as diabetes, obesity, depression, and affective disorders, supported by multiple publications, such as Obayashi et al. (2013) [43] and McFadden et al. (2014) [44]. The authors conclude by stating that, although the light that reaches us

from the sun contains a high irradiance at all visible wavelengths, its maximum is 480 nm, which is perceived by humans as a beautiful blue (e.g., a clear day in the middle of the morning). This is the most optimal wavelength to signal to an organism that it is day rather than night [43].

Experimental and epidemiologic studies suggest that light at night (LAN) exposure disrupts circadian rhythm, and this disruption may increase breast cancer risk. Ritonia et al. (2020) [45] found no association between residential outdoor LAN and breast cancer for either measure of LAN. The authors found no association when considering interactions for menopausal status and past/current night work status. Ritonia et al. [45] are consistent with studies reporting that outdoor LAN has a small effect or no effect on breast cancer risk.

Konis et al. [46] conducted a 12-week study of 77 patients in eight dementia care facilities with the assumption that increased exposure to indoor lighting with natural light could reduce depression and other neuropsychiatric symptoms. The authors stated that they found positive results, but that these results should not be interpreted as a definitive prescription to replace existing treatments and that further studies should be carried out on the subject.

Lai et al. [47] concluded from their studies on mice that blue light is harmful; moreover, epidemiological studies on humans were found to be inconclusive regarding positive or negative effects of the use of blue-light-blocking intraocular lenses (IOLs). In an experiment conducted with 18 groups of four rats that were exposed to light between 460 and 480 nm with intensities of 0.6 and 1.5 W/m², the authors concluded that the safe amount of time that these animals can be exposed to these irradiances is 12 h with an intensity of 0.6 W/m² and for 4 h with an intensity of 1.5 W/m² [48].

Roehlecke et al. [49] irradiated a culture of mouse retinal cells using blue light with a peak emission at 405 nm and an intensity of 10 W/m² and stated in their conclusions that oxidative stress was produced and reactive oxygen species (ROS) were generated. Torkaz et al. [50] (2013) stated that the retina is especially exposed to oxidative stress due to high oxygen pressure, UV exposure, and blue light promoting the generation of ROS. Nakanishi et al. [51] stated that cultured ROS cells exposed to blue LEDs with an emission peak at 470 nm and an intensity of 48 W/m² showed a significant increase in ROS occurrence.

Chamorro et al. [52] radiated human retinal pigment epithelial cells (HRPEpiC) using blue light emitting LEDs with peak emissions at 468 nm, using green light with peak emission at 525 nm, and using red light with peak emissions at 616 nm, as well as white light, in 12 h light–dark cycles. The authors observed ROS, cell DNA damage, and apoptosis (delayed cell death).

3.3. Measurements of Light Emitted by Luminaires and Electronic Equipment Used by Adolescents

There is a growing number of articles on the subject of light emitted by luminaires and equipment. In an article published in 2013, Hassoy et al. [53] noted that mobile phones are widely used by children and adolescents. The authors provide data from several countries including 76% phone use in Hungary, 79% in Sweden, and 94% in Germany.

In 2014 in Barcelona, the Spanish testing laboratory accredited by the Empresa Nacional de Acreditación (ENAC) FUTTEC S.L carried out, with a double monochromator spectrometer calibrated by the Centro Superior de Investigaciones Científicas (CSIC), different irradiance measurements on the blue ranges of mobile phones, laptops, and indoor lights in W/m² compared to the same ranges within the blue range of UVI 6 and UVI 9.

The measurements were made at the distances that the electronic devices are located from our eyes. Figure 3 shows a graph of the ultraviolet index (UVI) measurements (around five) given by the Department of Astronomy and Meteorology of the Faculty of Physics at the University of Barcelona. The maximum irradiance was observed around 480 nm.

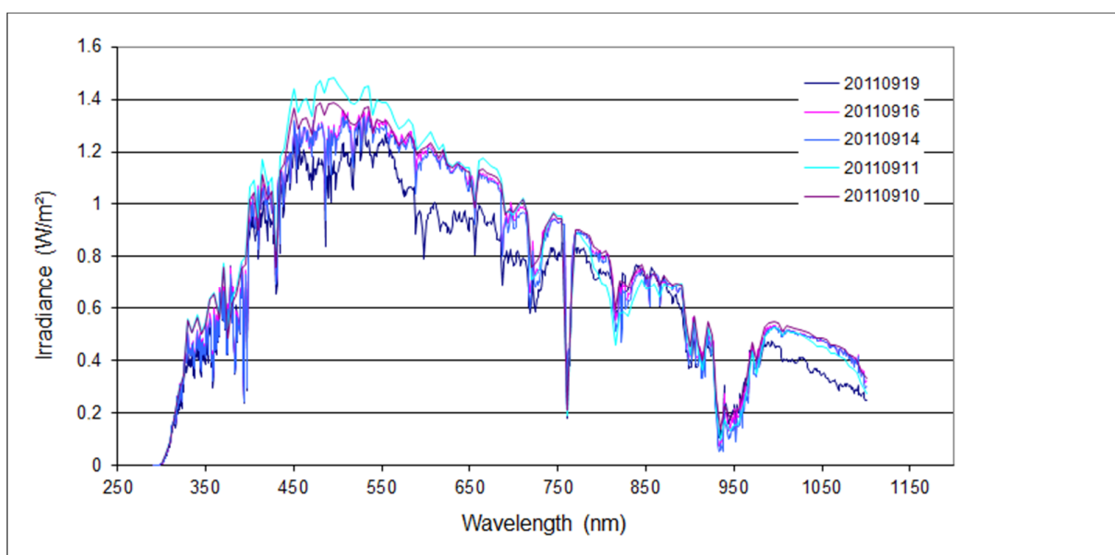


Figure 3. Several solar spectral distributions provided by the Faculty of Physics of the University of Barcelona [54].

These results were made public at the Congress of the General Council of the Official Associations of Pharmacists of Spain (CGCOF). Below are the results of the irradiance measurements of 10 nm between 400 nm and 600 nm performed by the FUTTEC test laboratory including:

- irradiance at solar noon on a spring day with a UVI of 9 measured by the Astronomy Department of the University of Physics of the University of Barcelona;
- irradiance at solar noon on a summer day with a UVI of 6 measured by the Astronomy department of the University of Physics of the University of Barcelona;
- a laptop screen with a blue background in a totally dark room. A laptop screen with a blue background in a lit room at working distance;
- emissions of a cold white light luminaire (6500 K) in an interior corridor at the distance from the ceiling indicated by regulations;
- display of a desktop computer at a working distance with a blue background in an illuminated office;
- irradiance in a work room of the PHILIPS company with the irradiance of a 2700 K LED light;
- a 4000 K LED light; and
- irradiance of a Samsung mobile phone screen with a blue background in total darkness.

In Figure 4, the green line represents measurements on a computer screen in a workroom, where the windows facing the street are very close. This is why the measured irradiance is superior to the irradiances of smartphones, computers, mobile phones, and LEDs, and similar in shape to the graphics of sunlight.

Escofet and Bará [55] show the analysis of two computer screens and two smartphones. The irradiance results from the computers are around 450 nm of $4 \times 10^{-3} \text{ W/m}^2$, and those from the two smartphones around 450 nm are $6\text{--}7 \times 10^{-4} \text{ W/m}^2$. In their article, they show the absorption of different filters to be placed in front of the screens to reduce the irradiance in the blue range and recommend their use.

In 2018, new measurements were made in an optics laboratory on an optical bench in total darkness with a double monochromator spectrometer from FUTTEC S.L. calibrated by the CSIC. The measured electronic equipment belonged to students studying optics who were asked to give their electronic equipment a blue background with maximum luminosity. The measurements were taken at the distance at which they said they would put the equipment in place to use it. A nanometer by

nanometer scan was performed from 350 to 500 nm to analyze the area in the blue range, as well as the irradiance peak. Table 1 shows the irradiance and peak light results from these measurements.

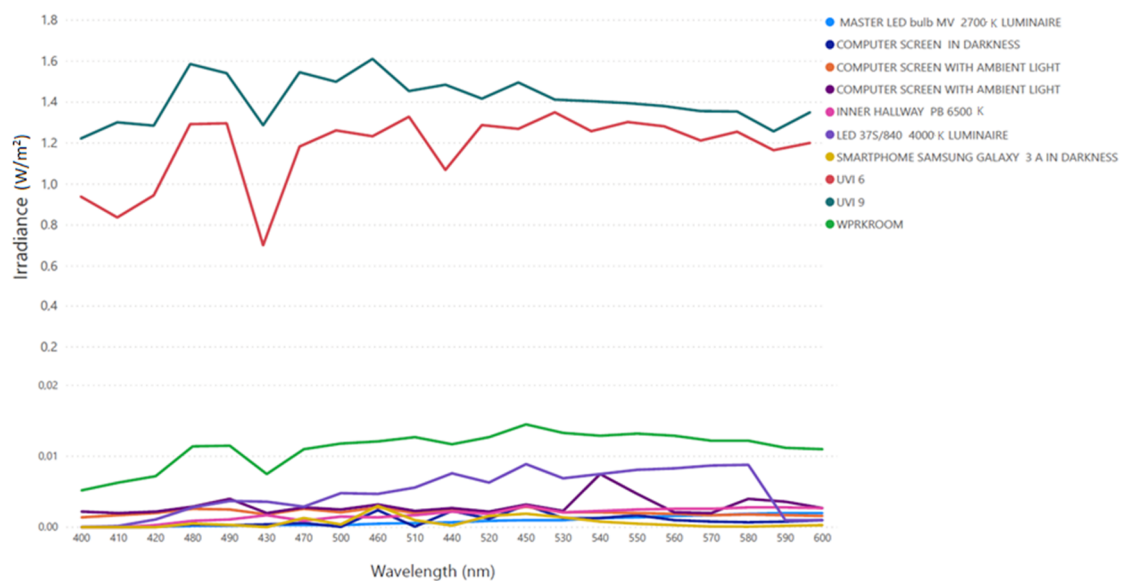


Figure 4. Comparison of the irradiance of artificial light sources with that of the sun. The 400–500 nm irradiance of electronic equipment for personal use, indoor lighting, and solar ultraviolet index (UVI) (modified vertical axis scale). Authors' own.

Table 1. Peak emission and irradiance of electronic devices. Results of the measurement of the peak wavelength and irradiance in the blue range of electronic equipment. Authors' own.

Model	Irradiance Peak Wavelength	Irradiance W/m ²
Laptop: HP Pavilion	445 nm	0.003597388
iPhone 6-S	448 nm	0.001446128
iPad sixth generation	448 nm	0.001565119
Samsung Galaxy J7	455 nm	0.001976249
Samsung S9	452 nm	0.000369329
iPhone 8 Plus	449 nm	0.000465317
iPad second generation	451 nm	0.003354588

3.4. Studies on the Effects of Artificial Light Sources on Adolescents

Several authors [56–59], have referred for years to the problem of mobile phone addiction, which they define in different ways as mobile phone dependence, the problematic use of mobile phones or cell phones, mobile phone abuse, and nomophobia (a fear of being without one's phone). Symptoms include preoccupation with the device, excessive use with loss of control, use of the device in inappropriate or dangerous situations, adverse effects on relationships, symptoms from lack of use (feeling angry, tense, depressed when the mobile phone is not accessible, constantly worrying that the battery will run out, etc.), and tolerance symptoms (the need for a better mobile phone, more software, or more hours of use). These symptoms are similar to those of substance dependence, which is why some researchers consider mobile phone dependence (MPD) to be an independent diagnosis.

A study was carried out in 2015 that surveyed 415 secondary school adolescents, among whom 251 were boys (60.48%) and 164 were girls (39.51%). The average age of the participants was 13.99 ± 0.8 years. The average time spent each day with a mobile phone was 131.77 ± 119.9 min. In this way, the prevalence of mobile phone dependence was demonstrated. Indian boy and girl adolescents comprised 33.5% and 39.6% of the study, respectively, and it was conducted using the International Classification of Diseases 10th edition (ICD-10), classification criteria for mental and behavioral disorder dependence syndromes [60].

LeBourgeois et al. [61] published an article on the effects of machine-emitted light on physiological circadian and warning sleep timers. They claimed that a high percentage of young people and adolescents have insufficient sleep periods. They referred to a 2004 article entitled “National Sleep Foundation. Sleep in America poll: Teens and Sleep”, in which a large majority of studies were shown to find an adverse association between electronics consumption and sleep health, as well as a short time in bed and reduced sleep time. U.S. population data show that approximately 30% of preschool children and between 50% and 90% of school-age children and adolescents do not sleep as much as they need to. Data from a study of 454 teenagers revealed that more than 60% go to bed with their mobile phones and more than 45% use their mobile phone as an alarm or as a light. In addition, recent studies of 2000 students in grades four through six indicated that sleeping close to what is defined as “a small screen” was associated with increased fatigue.

Additionally, Crowley et al.’s [62] recent findings indicate that prepubescent children compared to postpubescent adolescents have greater melatonin suppression under low (15 lx), moderate (150 lx), and bright (5000 lx) light exposure in the hours prior to bedtime. Turner and Mainster [63] stated that children are more sensitive to light than adults based on their eye structures featuring a larger pupil size and a higher lens transmission.

Another study was conducted on 9846 adolescents between the ages of 16 and 19, taking into account the type and frequency of electronic equipment used in bed and the hours spent in front of screens during rest time. Sleep variables were calculated based on time in bed, duration of sleep, latency time before sleep, and state upon waking after sleep. The results of the study confirm that the adolescents spent a great deal of time during the day and in bed using electronic equipment. The use of electronic devices during the day and night was associated with an increased risk of a short sleep duration, a long sleep onset latency, and increased sleep deficits. The conclusion of the study is that the frequent use of electronic equipment is as common in adolescents during the day as it is at night. These results demonstrate a negative relationship between the use of technology and sleep, suggesting that recommendations on healthy use could involve a restriction of device usage [64].

A total of 746 surveys were conducted by Feizhou Zheng et al. [65] with children in Chongqing, China between October 2011 and May 2012 with data such as mobile phone use, if they feel well, and other possible confounding factors. Fatigue was significantly associated with years of mobile phone use and daily call duration. Headache was also significantly associated with daily call duration. There was no significant association between mobile phone use and other physical symptoms in the children and no consistent association with fatigue. The Independent Expert Group on Mobile Phones (IEGMP) reported several possible reasons for such sensitivity, including the information below.

- Children are more vulnerable to potentially harmful agents than adults because their nervous systems are developing.
- For anatomical reasons such as the smallness of their heads, thinner skulls, and increased nerve conductivity of their brains, children can absorb more energy from mobile phones than adults.
- Due to their early and extensive exposure to these devices, children will tend to accumulate more harmful health effects.

Yoshimura et al. [66] conducted a study on the mobile phone use of 23 nursing students. The measurements of the mobile devices showed the peak light of the mobiles at 453 nm, and the values of illuminance produced by each of the mobile devices were 25.3 to 42.6 lx (simulating their use in a seated position) and 50.5 to 80.4 lx (lying down).

Bae [67], in an editorial in a Korean journal of medicine in 2017, referred to several studies on the mobile phone dependency of adolescents. Min referred to an article by Lin et al. [68], which stated that dependence on smartphones is a problem that has spread throughout the world and, based on the study, proposed diagnostic criteria for smartphone addiction. Min also referred to a study by Elhai et al. [69] that related the use of smartphones to anxiety and psychopathological depression. In the editorial, Min states that the studies being published allude to various physical and psychological

problems, including ophthalmological, orthopedic, and sleep disorders due to the use of smartphones. This supports the claim that adolescents are a group at higher risk for addiction because of their developing brains, as stated in the National Information Society Agency (KR) study, “Survey on smartphone overuse” (2017) and in Long J et al. [70].

On 5 October 2017, the Spanish National Statistics Institute (INE) published the “Survey on Equipment and Use of Information and Communication Technologies in Households. Year 2017”. The statistics show that the proportion of children (from 10 to 15 years old) who use information and communications technology (ICT) is, in general, very high. Thus, the use of computers among children is very widespread (92.4%) (even more so for the use of the internet (95.1%)). In 2016, the number of minors using the internet exceeded the number of those using a computer. The differences by sex were not very significant. By age, the results suggested that the use of computers and the internet was a majority practice among children aged ≤ 10 years old. In turn, the use of mobile phones was found to increase significantly (Table 2) after the age of 10, reaching 94.0% in the population aged 15 years old [71].

Table 2. Percentage of underage information and communications technology (ICT) users among children aged 10–15 years. Percentage of underage ICT users by gender and age [71].

	Computer Use	Internet Use	Cellular Availability
Total	92.4	95.1	69.1
Gender			
Men	91.1	94.9	68.2
Women	83.8	95.2	70.0
Age			
10	88.4	88.8	25.0
11	89.3	91.0	45.2
12	95.8	95.8	75.0
13	93.6	96.8	83.2
14	95.1	98.9	92.8
15	92.5	99.2	94.0

4. Lighting in the Classrooms

4.1. Classroom Lighting and Energy Saving

Mareno and Labarca (2015) [72] have suggested that the traditional daylight analysis methods provide very limited information compared to the new dynamic methods that integrate factors such as sky type and local light conditions. These methods reinforce the evaluation of applied daylight strategies in favor of integrated design. This is shown in the design of classrooms by the method of dynamic simulation, which provides quantitative information on the proposed strategies, taking into account the levels of illumination for the visual tasks of the students.

The methods and metrics that incorporate climatic variables have been studied in order to refine the climate data needed to apply dynamic methodologies. Climate-based daylight modeling (CBDM) allows the integration of different variations of light in the simulations in relation to the local climate, generating for a specific moment a series of predictions which, in general, are for each hour of a complete year. At the same time, passive design, as an architectural principle, seeks to provide comfort conditions within buildings by optimizing the design through the integration of environmental factors of the site, thus minimizing the use of active means for that purpose. Complementarily, design for energy efficiency seeks a specific purpose for it, providing the best environmental conditions to achieve visual comfort and good lighting quality, and using the least amount of energy possible.

From the perspective of architectural design, a poor conception of lighting strategies can have negative implications, such as increased use of alternative energies, or can directly affect users, creating situations of visual discomfort. Dynamic metrics based on climate data (CBDM) have created a new

perspective in the study of natural light by responding to the local climate, which accounts for daily and seasonal variations of daylight when combined with weather data. These have displaced traditional daylight metrics, like the daylight factor (DF), whose limitation is that it does not consider the dynamic aspects of light: the latitude, the different seasons, the different times of the day, the variations of the skies, and the orientation of the building [73].

The metrics developed and used in dynamic daylight performance measurements are based on the time interval in which the basal levels of illuminance and luminance are reached within a building. These time intervals typically extend throughout the year, based on external data such as annual solar radiation and depending on the location of the building [10]. Among the metrics whose analyses are based on the time variable, we have daylight autonomy (DA), useful daylight illuminance (UDI), and continuous daylight autonomy (DAcon), which have been given a more comprehensive evaluation based on climate files, the building's orientation, and the time that the building is occupied. Daylight autonomy (DA) sets an illumination value to guarantee autonomy to work only with daylight; however, we can have an exceptional autonomy without guaranteeing visual comfort, since by not setting an upper illumination limit, we can have too much daylight at certain times of the year.

The useful life of daylighting defines a range of illuminances that can be said to constitute useful levels of illumination [74]. What is new about this metric is that upper and lower limiting illuminance values are incorporated, while compliance intervals are set by integrating the concept of target ranges. The new series defined in 2012 were the useful daylight illuminance (UDI) "fell-short" (UDI-f), when the illuminance is less than 100 lx; the UDI supplementary (UDI-s), when the illuminance is greater than 100 lx and less than 300 lx; the UDI autonomous (UDI-a), when the illuminance is greater than 300 lx and less than 3000 lx; the UDI combined (UDI-c), when the illuminance is greater than 100 lx and less than 3000 lx; and, finally, the UDI exceeded (or UDI-e), when the illuminance is greater than 3000 lx [75].

Al-Khatatbeh (2017) [76] stated that in classrooms, light levels are directly related to energy consumption due to the use of artificial light. Therefore, this study aimed to improve visual comfort and energy efficiency in existing classrooms by investigating various adaptation methods for passive daylighting techniques in north-facing classrooms at the Jordan University of Science and Technology (JUST). The data from this research were obtained using computer simulations and real measurements. The combination of the office window and the south-facing anidolic ceiling provided about 62% of the light needed for the classrooms, and reduced the energy consumption required for lighting and heating by 16.3%. According to Yener [77], classroom lighting should be adequate for activities such as reading and writing on the blackboard and at desks. Kruger and Dorigo [78] found that each country has its own classroom lighting standards, but they all fall within the 300–500 lx range. Many are based on guidelines published by the Illuminating Engineering Society of North America (IESNA) and the European Standards (CEN).

Currently, the tools that are available to evaluate green buildings include the evaluation of Indoor Environmental Quality (IEQ) and obtaining the health of the occupants, and one of the elements that can be evaluated is visual comfort. Adaptive re-use is one of the well-known strategies to improve the sustainability of existing buildings in order to reduce material, transport, and energy consumption, as well as pollution levels [79]. Changes in building function have degraded the level of many buildings' IEQs, including their indoor lighting performance. The performance of indoor lighting is generally measured by the lighting level (E), daylight factor (DF), and the uniformity ratio. The illuminance level may vary in each room, with their different functions.

$DF = E_i/E_o \times 100(\%)$, where E_i = indoor illuminance, E_o = outdoor illuminance (varies from 20–130 klx), and DF = daylight factor.

Based on previous research, Susan and Prihatmanti (2016) [80] stated that lighting in educational institutions is a critical factor, because poor lighting is not only detrimental to the visual comfort of the occupants, but could also lead to eye fatigue.

4.2. Problems with Poor Lighting in the Classroom

Winterbottom and Wilkins [81] measured, in 90 secondary school classrooms, with the variable of flicker, the lighting of the desks and the blackboards. The results showed that 80% of the classrooms were illuminated with fluorescents, which can cause headaches and impair visual task performance. While the illuminance (from excessive day and artificial lighting) was in excess of the recommended levels in 88% of the classrooms, in 84% it exceeded the levels to a degree that visual comfort would decrease. The lighting was not always adequately controlled, depending on the class design and infrastructure. The ambient light needed for close work at desks reduced the contrast of images. Venetian blinds in 23% of the classrooms had spatial features suitable for inducing glare. These findings provided information on small-scale reports linking student performance, behavior, and learning to classroom lighting. In rooms where there is no uniform lighting, when the immediate task area is brighter than the surrounding area, the effects of glare can be significant. Compared to the recommendations of the Chartered Institution of Building Services (2004) [82], the lighting varied from inadequate to excessive. It is important to note that the data for this study were collected in the summer months, when daily lighting may have been higher than the average for the year.

Winterbottom and Wilkins [81] stated in their article that there are numerous studies that have also noted changes in behavior under particular forms of lighting. Schreiber (1996) [83] suggested that children are more relaxed and interested in activities when classroom brightness is reduced; while Shapiro, Roth, and Marcus (2001) [84] found that maladaptive behaviors were less frequent under indirect full-spectrum fluorescents. Rittner and Robbin (2002) [85] indicated that daylight helps students retain and learn information. Some authors have emphasized the importance of daylighting, but with the need for integrative systems of natural and artificial light.

CIBSE (2004) [86] provides lighting design recommendations for different types of classrooms, in the range of 300 lx to 500 lx; the adoption of such values helps to restrict glare to reasonable levels (it is worth noting that a new installation with new lamps and clean surfaces can provide 25% more lighting than the designed lighting, and only half as much as the initial lighting is present when the lamps are old and dirt has accumulated).

Ho et al. [87] conducted a study to minimize classroom lighting costs in Taiwan by taking advantage of natural light. In their article, they state that there is ample evidence of the damage caused to children's vision as a result of poor lighting conditions in classrooms. Optimal shading of classroom windows is important to improve daylight illumination in the subtropics.

Guan and Yan (2016) [88] state that daylight varies greatly due to the movement of the sun, changing seasons, and various climatic conditions. Customized static light assessments, known as static daylight assessments, representing simulations of only one time of the year or one time of the day, are inadequate for evaluating the dynamics of daylight variability. Using the graphic tool Temporal Map to display annual daylight data, this study compared different passive architectural design strategies under climatic conditions of five representative cities and selected the most appropriate schematic design for each city, which in turn was integrated with the Chinese academic calendar to obtain an improvement in occupational time. This modified map connected design work with human activity, making the daylight evaluation more accurate and efficient. In addition, the prevalence rate of myopia is extremely high among young Chinese people according to current government statistics [89]: up to 40.89%, 67.33%, and 79.2% in primary, junior, and high school, respectively, and remarkably, 84.72% in university. In fact, the database, derived from the national adolescent health survey conducted every five years, shows that nearsightedness ratios have been steadily rising in recent decades [89–91]. Meanwhile, high levels of light have been shown to have preventive effects for myopia [92,93]. Given the potential energy savings and health benefits for students, improving the quality of light in such environments must be a priority.

4.3. Effects of Classroom Lighting on Student Performance

Improving student progress is vital to a nation's competitiveness. Scientific research shows how the physical environment of classrooms influences student progress. The structural facilities of buildings have a profound influence on learning. Inadequate light, noise, poor air quality, and poor heating in classrooms are factors known to be relevant to poor student progress. Students exposed to more natural light (i.e., daylight) in their classrooms perform better than students exposed to less natural light [94]. Cheryan et al. [95] conducted a study of more than 2000 classrooms in California, Washington, and Colorado, in which they found students who were exposed to a large amount of daylight in their classes had better reading and math test scores than students who were exposed to less daylight in their classes (2–26% higher, depending on school district), even after statistical control of the student population that included race and socioeconomic status [96]. According to the National Center for Education Statistics (Alexander and Lewis, 2014) [97], 16% of schools with permanent buildings and 28% of schools with temporary buildings (i.e., portable) have unsatisfactory or very unsatisfactory natural lighting. Although the incorporation of natural light can be beneficial, it should be done with care to avoid visual discomfort [95].

Choi et al. (2014) [98] investigated the relationship between indoor environmental quality (IEQ) in university classrooms as a whole and student outcomes, including satisfaction with IEQ, perception of learning, and course satisfaction. The results were collected from the students.

Lighting conditions have always been an important IEQ criterion, including the sources of natural and artificial ambient and task lighting. Each of these elements has a unique role in user experiences within the built environment. Exposure to various types of light may be associated with psychological responses to human performance. Studies conducted in elementary school settings found a positive and significant correlation between the presence of daylight and student performance across three different school districts. Daylight received through skylights has a positive effect on students in their classrooms. Subsequent studies comparing classrooms with a large amount of daylighting with classrooms with less daylighting showed a 21% increase in student performance [96,99,100].

López-Chao et al. (2020) [101] state that empirical research has shown the influence of architectural spatial variables on student performance. Their article explored the relationship between the learning space and mathematics and artistic activities in 583 primary school students in Galicia (Spain). For this study, the Indoor Physical Environment Perception scale was adapted and validated, and utilized in 27 classrooms. The result of this exploratory factor analysis evidenced that the learning space has three structural categories: workspace comfort, natural environment, and building comfort. Sick building syndrome (SBS) shows that poor quality environments harm the health of users. Specifically, students perform better in brighter classrooms. Similarly, young children can differentiate their lighting needs according to the task at hand, while visual comfort is a key element for artistic activities, especially for drawing.

Heschong [96] included a focus on solar lighting as a way to isolate daylight as a source of illumination, and separated the effects of illumination from other qualities associated with light entering through windows. In this project, the author established a statistically convincing connection between daylight and student performance, and between lighting and retail performance. The author analyzed test score results for over 21,000 students from three districts located in Orange County, California; Seattle, Washington; and Fort Collins, Colorado. The author reviewed architectural plans, aerial photographs, and maintenance records, and visited a sample of the schools in each district to classify the daylighting conditions in over 2000 classrooms. Each classroom was assigned a series of codes on a simple 05 scale indicating the size and tint of its windows, the presence and type of any skylighting, and the overall amount of daylighting expected.

Kuller and Lindsten [102] are private investigators who followed the health, behavior, and hormone levels of 88 8-year-old students in four classes over the course of a school year. The four classes had very different daylight and artificial lighting conditions: two had natural light while two did not, and two were illuminated with warm white light emitting fluorescents (3000 K) while two had

very cold white light emitting fluorescents (5500 K). The researchers found a significant correlation between daylight level patterns, hormone levels, and student behavior, and concluded that the practice of having no windows in classrooms should be abolished.

Wilkins (2002) [103] analyzed the performance of primary school classroom lighting given the impact that natural light has on the educational experience of students. Boyce [104] and Dudek [105,106] showed that natural light increases productivity, positively affects human performance, and has biological effects on the production of the hormone cortisol, regulating light-dark cycles, and the ability of students to concentrate. Ultimately, this is a relevant environmental aspect to be studied in order to understand the results of daylighting of different environments.

5. Existing and Developing Regulations Related to the Non-visual Effects of Light Absorbed through Our Eyes

In 2011, the European Commission published the Green Paper “Let’s light up the future: Accelerating the deployment of innovative lighting technologies”. This document raises concerns about blue light’s potential risks to vision. The Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) released a document in 2012 entitled “Health effects of artificial lights”, which explored the scientific evidence on the potential impacts of artificial light radiating into the visible spectrum on human health [107].

In 2013, the International Commission on Illumination (CIE) published the “Report on the first international workshop on circadian and neurophysiological photometry”. This document features multiple references to the article mentioned in this paper by Lucas et al. [108]. This CIE paper describes the five photoreceptors located in the human eye (the three types of cones, the rods, and the ipRGCs) and notes that they all influence the stimulation of melatonin synthesis, although the paper concludes that much remains to be determined about their mechanisms of action. The importance of pupil contraction in the non-visual effects of light absorption is also mentioned [109].

In 2016, the CIE [110] published the “Research Roadmap for healthful interior lighting applications”, which refers to multiple studies with statements such as the following.

- The use of lamps with an illuminance of 10,000 lx for 30 min has been tried with positive results for the treatment of people who have been diagnosed as suffering from seasonal affective syndrome (SAD).
- Bright white light can have an activation effect that is linked to increased alertness, reduced drowsiness, and increased levels of vigilance both during the day and at night. During the day, high exposure to white light can modulate the brain’s cognitive functions such as logical reasoning and creativity.
- People choose places with higher light intensity when they feel low in vitality and alertness. During the day, periods of exposure to bright light (more than 1000 lx) can lead to better social and emotional interaction. This may be due to a direct effect of bright light on serotonin metabolism.

In 2017, the CIE [111] held a working meeting: the CIE stakeholder workshop for temporary light modulation standards for lighting systems. Current lighting systems vary widely in that their light output shows temporary variations or flickering (temporal light modulation, TLM). Temporal light modulation (TLM) is known to affect human visual perception, neurobiology, and behavior, sometimes adversely. Many organizations have developed standards and regulations, and certifying organizations have been active in research focused on these issues. Some researchers are studying these effects, but such activities are currently uncoordinated and at risk of being inefficient. The CIE, with support from Energy Efficiency Canada, the national association of electricity manufacturers, Philips Lighting, BC Hydro, and Research Canada, agreed to hold a stakeholder workshop in Ottawa, Canada on 8–9 February 2017. The objective of this meeting was to create a roadmap for research, offer recommendations, and develop regulatory activities related to the temporary variations of light from

lighting systems to accelerate the international regulatory development process in an efficient manner and avoid the overlap and duplication of such efforts.

In 2018, the CIE [112] published a document titled “ED/IS 026/E:2018 CIE System for metrology of optical radiation for light responses influenced by intrinsically-photosensitive retinal ganglionic cells”. The introduction of this paper states that light is the main synchronizer of human biological clocks and may result in the acute suppression of nocturnal melatonin release. While the functioning of cones and rods in the vision process are well known, the function of spectral sensitivity and a quantitative and qualitative analysis of melatonin-based photoreception remain unexplored.

The aim of this international standard is to define the role of spectral sensitivity, quantify it, and measure it to describe visible radiation and UVA according to its ability to stimulate each of the five types of photoreceptors, i.e., how much each contributes to the melatonin content of intrinsically photosensitive retinal ganglion cells (ipRGCs), and thus their mediation on the non-visual effects of light on humans. This international standard is applicable to visible optical radiation of 380–780 nm.

This international standard does not give information on particular lighting applications or a quantitative prediction of the response of ipRGCs; it also, does not mention health or safety issues, such as the results of light treatments, flickers, or photobiological health.

Experts around the world are collaborating on the development of this standard which states that light is the main synchronizer of human biological clocks and can lead to an acute suppression of melatonin release at night.

6. Results and Discussions

Throughout this review, we have examined works by scientists who are experts in different branches of knowledge related to humans. These studies confirm that human beings are designed to carry out all their physiological and cognitive activities during the day and to rest at night. Our civilization has changed the natural light–dark cycle that humans experience. Researchers have expressed concern over electric lighting as a potential disruptor of the natural light–dark cycle [16].

Some articles [10,59,113] have stated that LED lights are dangerous because they emit much more blue light than other types of lights and the sun. In studies on the development of LEDs, several examples of technical publications have refuted the theory that new light sources radiate more blue light than traditional sources (rather the opposite), including the sun. New LED-type light sources do not necessarily produce a higher percentage of blue light than traditional light sources (mercury vapor lamps, halogens, etc).

In addition, under normal working conditions, in accordance with current lighting legislation, around 500 lx should be received at one’s workplace, regardless of the type of luminaire used.

If we compare the illuminance emitted by lights against those of solar irradiance, we find that a cloudy day in the northern hemisphere will produce about 3000 lx; about 50,000 lx on a sunny summer day in Spain; and about 100,000 lx in the tropics. Thus, we can conclude that the possible risk of blue light on the retina under general lighting indoors is low to very low, even if one uses cold color temperatures as general lighting.

The neurons responsible for the melatonin, serotonin balance (ipRGCs), are sensitive to light from UVA to red, with their peak in blue. By absorbing light at the beginning of the day, melatonin is eliminated and replaced by serotonin [59]. Within the range of the visible spectrum, the most abundant energy we receive from the sun is blue, and its peak is approximately 480 nm. This is, therefore, the peak of the maximum sensitivity of melatonin. Beings who are active during the day have evolved by adapting to sunlight [114].

Since the discovery of these neurons 25 years ago, the scientific world has not stopped discovering evidence of the synchronization of our organs, and even our individual cells, with the light and dark cycles of nature. These discoveries are considered so important for the scientific world that the 2017 Nobel Prize in Physiology and Medicine was awarded jointly to Jeffrey C. Hall, Michael Rosbash,

and Michael W. Young for their discoveries of the molecular mechanisms underlying the control of circadian rhythms.

Artificial light has facilitated great advances in many fields, but it can also pose a risk as it can alter the natural cycles of sleep and wakefulness, in many cases reducing the hours of sleep by people being able to continue to carry out activities during the night period. An alteration of sleep can pose a risk to health, leading to chronodisruption. Chronodisruption is an alteration of the internal temporal order of physiological, biological, and behavioral rhythms. If it becomes chronic, asynchrony, advancement, or retardation of the peripheral clocks may occur [17].

Epidemiological studies show that chronodisruption is associated with an increased incidence of metabolic syndrome, cardiovascular disease, cognitive and emotional disorders, premature aging, and some cancers such as breast, prostate, and colorectal cancer, as well as the worsening of pre-existing pathologies.

The scientific community has shown, with multiple studies, that humans need biorhythms to receive sufficient amounts of light in the blue range during the day but in a different proportion depending on the time of day. Erren and Reiter define correct lighting as photohygiene. This factor is already considered so important for health that the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) included shift work as a cancer-inducing factor in 2010.

Many articles recommend that the reception of artificial light should be as close as possible to daylight. It should be more intense with a higher proportion of blue, with a maximum value at mid-morning, which should then decrease in intensity and quantity, mainly in its proportion of blue. For more than ten years, correct or incorrect lighting has been associated with the good or bad physical and psychological conditions of people [17].

Increasingly more scientists are advocating the study and development of luminaires that are more in line with sunlight [21], and there is a call for interior lighting that not only differs throughout the day, but also differs depending on the seasons based on the response to their cumulative absorption, i.e., there should be more intense irradiance in public spaces (including schools) in autumn and winter and less in spring and summer [39,40].

Experiments have been carried out on patients with dementia and other neuropsychiatric pathologies where researchers improved the symptoms of their illnesses by receiving light closer to daylight. This light was more intense and featured a greater amount of light in the blue range than that which they received in the centers where they reside [31].

Notably, Glickman et al. [20] observed that, although it was initially thought that an illuminance of 2500 lx is necessary to suppress nocturnal melatonin in humans, under certain conditions, values as low as 10 lx [114], and possibly 1 lx or less, can suppress melatonin in humans. This would support the recommendation to sleep in complete darkness since, if we have any lights on, that very small amount of light could pass through our eyelids.

The current majority of studies states that the minimum amount of light that we receive from 9:00–10:00 p.m. will delay the transition from serotonin to melatonin and, therefore, delay the process of rest that is essential for health. Moreover, the sudden reception of low-intensity light delays the process since this light is not received for at least 40 min [27]. If these disorders persist over time, chronodisruption and undesirable cortisol levels may occur. Scientists have related this disorder to metabolic syndrome, cancer, obesity, diabetes, cardiovascular disease, and cognitive and affective disorders.

The accredited test laboratory FUTTEC measured the amount of blue light emitted by various electronic equipment used by children and adolescents in 2014 and 2019. The results show that the irradiance in the blue range of these devices (at the distance they are commonly used) is between 1000 and 10,000 times lower than what we can receive at the same time from the sun on a spring day with a UVI of 6. Compared to a day with a UVI of 9, this amount would be up to 30% higher on a spring day.

Based on these results, it is not considered plausible that this equipment is harmful to the retina, as our eyes can survive 1000 to 10,000 times more light than they receive from these devices from the sun.

Yoshimura et al. [115], in their study on the use of mobile phones among 23 nursing students, found the peak of light of the mobile phones at 453 nm, and the illuminance in the seated measurements were from 25.3 to 42.6 lx; lying down, these values ranged from 50.5 to 80.4 lx. The authors logically note that this amount of light is not likely harmful to the eye (as per other studies) but can affect circadian cycles and sleep quality.

Escofet and Bará [55] studied the emissions of two computer screens and two smartphones with irradiance results from the computers of 4×10^{-3} W/m² around 450 nm and $6\text{--}7 \times 10^{-4}$ W/m² from the two smartphones. The authors recommend the use of filters to protect from such irradiation. This irradiance, however, is between thousands and tens of thousands of times lower than the irradiance we receive from the sun.

An important issue for optometrists is that if we remove the part of the spectrum that we can most comfortably accommodate at close distances, as explained in the introduction to this paper, we would have to make more accommodation efforts and would require greater light intensity to do the same job. Would that not be more counterproductive than removing a small percentage of blue?

The results of the measurements and scientific publications show that the composition of light used for indoor lighting can influence the balance between serotonin and melatonin and therefore, our circadian cycles.

- Analysis of the possible negative effects of blue light from electronic devices on the eyes of adolescents

Various news media have reaffirmed the results (according to scientific studies) that suggest the damaging effects of blue light emitted by sources of artificial light on the retina (both LED lights and computers and mobile phones). These results are supported by published articles that correlate a greater exposure to light emitted by LEDs with a greater absorption of light in the blue range which, as a consequence, can accelerate the development of cataracts, pose a greater risk of damage to the retina, and, therefore, increase the prevalence of age-related macular degeneration (AMD). Many companies in the optical sector offer filters that absorb much of the blue light emitted by electronic devices to protect children and adolescents from this hypothetical risk.

After observing the prevalence of this concern, a search was made for scientific articles that corroborate this concern. The aim was to find an article showing the results of the irradiation of cell cultures or exposure to guinea pigs via the light actually emitted by this electronic equipment.

Notably, all the studies to date that note the possible damage from blue light in living tissue, especially the retina, have been carried out on cultures or living animals using monochromatic LED sources (emitting only in the most oxidizing part of the blue spectrum), with significantly higher irradiance levels than those actually emitted by electronic equipment.

Moreover, the experimental animals used include mice and rabbits, which are nocturnal animals whose visual systems are much more sensitive to light than those of humans, without any kind of algorithm or objective method to transpose these results into the possible effects on humans.

As a result, we believe that it is not possible to directly associate ICT's emissions with the possible real risks in the retinas of adolescents.

- Studies on the effects of artificial light sources on adolescents

There is an increasing number of publications by researchers (mainly from Asian countries) that relate low indoor lighting and natural light to the increase in myopia among children and adolescents worldwide, which in some countries, such as Singapore, involves more than 90% of children. The specific causes are unknown. No article has provided conclusive results [112]. This pandemic remains a challenge for the scientific community.

The dependence and addiction due to the indiscriminate use of mobile phones by children and adolescents all over the world already have attention within the scientific community, (e.g., nomophobia). This is a different problem from chronodisruption described above.

There is talk of a greater risk in children than in adults due to physiological reasons such as increased nerve conductivity and unwanted effects such as headache, dizziness, sleep problems, insomnia, dependence syndrome, and mental or behavioral disorders [56–59,67,115].

According to the results of the INE 2017, the percentage of minors who use a mobile phone in Spain reached 94% by the age of 15, making it a health priority to provide relevant information and control the use of ICT by adolescents [71].

- Existing and developing regulations for the non-visual effects of light absorbed through our eyes

The authorities in the European Community, through the CIE, and internationally through the International Organization for Standardization (ISO), have been sensitive to the concerns of the scientific community, and groups with experts in different fields have been increasingly established to study the non-visual effects of light.

In the development of this study, the work of the European Community was broken down as a Green Paper published in 2011. When this document was published, the scientific community was not yet aware of the technological revolution of the new LED lighting systems to come, especially from the perspective of their possible influence on people's states of mind.

European bodies studying health risks, such as the SCENIHR and the CIE from 2012 onwards, have gradually entered into the exciting study of this new field of science.

Concern over ICT irradiance is growing. This concern is reflected by the proposal produced at the end of 2018 for a group of experts from the CIE and ISO to jointly create a new document (integrative lighting) to use this research for the development of standards that define the composition of light in each area in which it will be used.

Lighting in the Classroom

- Classroom lighting and energy saving

The problems generated by the excessive consumption of fossil fuels and their effect on the fragile balance of our planet are well known, and a reduction in expenditure due to a decrease in energy consumption would allow countries to use these funds for the health or education of their inhabitants. Therefore, the reduction of energy consumption must be a priority for all public administrations, both for the savings it would entail and for the reduction of emissions of polluting gases [79,82,88,89].

In recent years, publications have appeared on studies and proposals for new parameters for cataloging buildings (IEQ), for specific data analysis of the parameters to be studied (CDBM), and on different parameters for obtaining more specific data, taking into account variables such as the amount of light at each time of day and season (DF, DA, UDI, DAcon, UDI-e, UDI-f, UDI-s, UDI-a, UDI-c) [72–75,79].

- Problems with poor lighting in classrooms

Studies on classroom lighting in this century and last century have reflected the widespread concern around obtaining the best possible lighting for children. We found an abundance of publications that discuss the unwanted effects on children of having classrooms that are either under-lit or over-lit [79,81,82]. The problems of inadequate illumination can be divided into temporary physiological problems of the visual system, psychological problems, and permanent problems of the visual system. For many years, there have been publications on possible temporary physiological disorders of the visual system, such as glare, headache, and/or fixation problems [81,82,85,87]. Some authors have realized, from the results of their studies, that poor lighting, whether natural or artificial, has notable negative effects on children's performance and mood [84,85].

The current pandemic of child myopia is an issue of global concern, but it is especially of concern in Asian countries, where it is most prevalent. One of the theories proposed by scientists who study this problem is that this increase in child myopia may be due to the short amount of time that children are outdoors receiving natural light. The recommendation for indoor lighting is between 300 and 500 lx, while outdoor light even on a cloudy day is tens of thousands of lx [90–94,116].

Figueira et al. [116] show that 1-h and 2-h exposure to light from self-luminous devices significantly suppressed melatonin by approximately 23% and 38%, respectively. The authors' previous studies suggest that adolescents may be more sensitive to light than other populations.

- Effects of classroom lighting on student performance

In 1992, the researchers Kuller and Lindsten [102] published an article in which they associated insufficient light levels with inadequate levels of hormones, leading to negative effects on children's behavior, and recommended that there be no classrooms built without natural lighting. At the time of their study, the relationship between light and the pineal gland and biorhythms was still unknown. Later studies found a relationship between correct artificial lighting or a combination of natural and artificial light and better performance of students in the classroom [98–101].

The influence of light on people's moods remains a subject of study today, throughout the scientific world. Official and scientific bodies involved in the world of lighting, such as the International Committee on Illumination (CIE) and the Lighting Research Center, have been researching and publishing studies for decades relating to the possible effect of lighting on the moods of students in the classroom, and the influence of this on their learning ability and their performance [102,109–112,116].

7. Conclusions and Recommendations

The functioning of human biorhythms responds to the proportion and intensity of the light we receive, whether natural or artificial. We are light-based beings designed to live with the rhythm of sunlight. Published articles that refer to the possible damage of blue light emitted by electronic equipment or LED lights do not scientifically prove that such equipment can damage the retinas of its users, including teenagers.

According to the research conducted so far, the light received from luminaires at night and from the electronic equipment used by adolescents, however low, is believed to have a negative influence on the balance of circadian cycles and on the quality of sleep.

Numerous studies around the world have come to the same conclusion. There is a growing pandemic of myopia in children and adolescents in certain areas of Asia, such as Singapore and South Korea, that exceeds 80%. This pandemic is suspected to be related to the use of electronic devices, but so far, its direct cause and possible solutions remain unknown.

The new generation of LED lights whose blue light intensity can be increased without increasing the illuminance, makes it possible for the professionals responsible for educational centers to recognize and alter the composition of their centers' lights since this composition can influence the "mood" of the affected people, including adolescents.

No publications were found on the composition of light in adolescent training centers or the psychological responses to it. For all these reasons, there is growing concern among international bodies, both at the European and the global level. These bodies have created groups of experts to urgently develop regulations to control the composition of the lights in new luminaires.

Based on the conclusions of this review, the following control or preventive measures are suggested. These measures could be promoted by administrations, educational centers, and families.

- Develop a "manual for the good use of electronic equipment by adolescents".
- Public and private managers should train the professionals in charge of the maintenance of public buildings, in this case schools, so that they can acquire the necessary knowledge for the correct acquisition and assembly of the lights to be placed in their educational centers.

- Make this circumstance known to the public bodies responsible for consumer protection, so they can inform people. Thus, when consumers acquire new luminaires for their homes, they can consider the proportion of blue light those luminaires contain due to their non-visual effects.

7.1. Limitations of Study and Foresight

The difficulties of this study stem from the scarcity of existing research in this field. The effects of continuously increasing or decreasing the percentage of blue light in a systemic way are unknown for human beings and, therefore, for children and adolescents. This is because, until a few years ago, it was not possible to make luminaires with alterable light components.

There is no possibility to control the luminaires that are being made in real time for two reasons: (1) any company or person can buy LEDs, group them, and use a programming system with a remote control to change the proportion and composition of their light as desired and (2) as there is no legislation on the non-visual effects of light, the proportion of blue light cannot be legally limited.

Due to these limitations, no concrete recommendations can be given to safely improve the health of adolescents. The scientific study of the effects of non-ionizing light on living beings is known as photobiology. This field does not currently exist as a separate subject, but is a new branch of knowledge that involves dermatologists, ophthalmologists, physicists, opticians, and chemists, each in their own fields. The aim of photobiologists is to integrate the specialty into all degrees of training in the health field (pharmacy, medicine, veterinary medicine, architecture, and engineering related to animal and plant biology).

Given its relevance to healthy human functioning, this content should be integrated into the curriculum from the earliest stages of education, with greater emphasis on the secondary and high school stages and the professional branches related to the field. In this sense, students should be aware of the impact of healthy ethical light in different contexts:

- greater precision and safety for patients who have light applied to their light treatments,
- improving the quality of life of tabulated animals by receiving light much more similar to that of the sun;
- a higher quality and optimization of greenhouse crops by irradiating them with light that is the most similar in each case to that of genetically designed crops; and
- finally, improving the health of all humans, including adolescents, by providing much healthier light inside buildings. The ideal lighting conditions involve the provision of natural light according to the time of day and the season, so that artificial light processes can radiate with light that is as similar as possible to that received when going out onto the street.

Therefore, the establishment of natural or artificial lighting according to natural parameters should also be a priority issue in the design and construction of new educational centers, as well as in the lighting of existing centers, to facilitate the transformation of toxic light into a new ethical–healthy model. In this sense, it is also necessary to train senior educational managers (central and autonomous community administration staff, as well as the directors or presidents of educational centers).

Additionally, this research offers a framework for study and reflection that will allow national and international governments to regulate lights in order to promote naturalization processes and new models that are applicable to the domestic, health, professional, and educational fields, thereby facilitating the incorporation of new measures and training that will make it possible to overcome the lack of existing regulations and training.

7.2. Lighting in Classrooms

The lighting of school classrooms has changed from being mostly mercury vapor lamps that emitted a peak in the blue range, another in the green range, and another in the red range but with a wide spectral distribution, to being LED lighting, for which the composition of the light and the proportion of each part of the visible spectrum that the students now receive is different to that received

from fluorescent lamps. LEDs do not emit a wide range of blue (blue LEDs do) but, as their emission is centered around 460 nm, even though the luminaires have a quantity of lx similar to that which would be obtained if a fluorescent lamp were measured with a lux meter, the effect of the proportion of blue on the melatoninergic receptors could be very different. Do those responsible for the maintenance of educational facilities understand the quantity of blue from the new LED luminaires they are installing and, therefore, the light that the students receive with the new LED luminaires, and how it differs from that which they received before?

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