SUSTAINABILITY AND ECOLOGICAL TRANSITION IN THE POST-COVID ERA

Challenges and Opportunities in the Face of Climate Change and Energy Transition

Ricardo García-Mira
Petra Schweizer-Ries
Cristina García-Fontán
(Editors)

Xoan Vicente Viqueira
Institute for Psychosocial Studies and Research

In recent years we have seen the need for changes emerge in the global context from both the social and ecological point of view. More recently, over the last three years, the Covid19 crisis and the climate change with which it is related, through the breakdown of the natural barriers that separate us from other species, is an example that we can go further from this return point and placing ourselves in a context of maximum interest. What is happening with this, therefore, does not take us by surprise, considering that we can clearly identify its anthropocentric origin and how it is related to climate change, from the alterations that human beings have caused in the cycle of ecosystems that maintain equilibrium at the planetary level.

Psychology has taught us that there is no single point of view, and that different theories explain the paralysis of society in the face of the urgency of undertaking effective and efficient climate action. On the other hand, different interests coexist in interaction within a social system. Manufacturers and producers observe nature with different perspectives than users, conservers and consumers, who, in turn, differ in different identities and ideologies, some oriented to act on the improvement of clean production, while others are more focused on reducing the impact by transforming consumption. Some organizations and social movements are oriented towards green production, while others call attention to the need to reduce demand, to go with de-growth. Development and growth, therefore, have occupied different positions in the public debate.

Meanwhile, whoever one has to define the policies that mark the trajectory to follow, in one direction or another, define guardrails to build a regulatory system with sustainability governance and broad participation. The development model has to be sustainable, regenerative and healthy and generate global ideas and values that permeate education and the social system with ethics, convictions and common objectives, which are authentic reference points of respect for planetary boundaries. In this context, the energy transition must begin by understanding what a transition is and why the way in which energy is managed is important within that transition. Generating interdisciplinary knowledge about this is important to be able to design a de-coupling plan to the different economic, technological, ecological, cultural and social ingredients of this transition of the whole system.

SUSTAINABILITY AND ECOLOGICAL TRANSITION IN THE POST-COVID ERA

Challenges and Opportunities in the Face of Climate Change and Energy Transition

Ricardo García-Mira
Petra Schweizer-Ries
Cristina García-Fontán
(Editors)

Xoan Vicente Viqueira
Institute for Psychosocial Studies and Research

06 / CONTRIBUTIONS FROM LIGHTING RESEARCH TO SUSTAINABILITY AND COVID-19 PANDEMIC

Graciela Tonello*
**National University of Tucuman, Argentina*
**Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina*

ABSTRACT

Besides vision, light can impact other processes such as circadian, neuroendocrine, and neurobehavioral responses. It is called non-visual effects of light because they are not directly involved with image formation, and they became an additional dimension in the traditional objectives of architectural lighting, which should provide the proper light for visual performance, for visual comfort, for the aesthetic appreciation of the space and for energy conservation. For instance, in working environments, light must serve not only to meet task demands but also for comfort and health.

People respond to environmental exposure through a holistic process composed of psychobiological correlates. To date, the most studied light-reactive hormone is melatonin since light can have an acute suppressive effect on this hormone. As to psychological states, seasonal affective disorder (SAD) probably constitutes the best example of light's effect on mood and behavior, and the abnormal pattern of melatonin secretion in SAD sufferers is still the main hypothesis as to the genesis of this disorder.

This conference aims to show the possible contributions from the field of lighting research to covid-19 pandemic and to post pandemic economy in terms of melatonin related health and wellbeing, vitamin D production in response to ultraviolet radiation on the skin, and the concept of sustainable lighting design referred to efficient lighting technologies such as LEDs, as well as guidelines to minimize circadian disruption and to improve productivity.

Keywords: Covid 19; Sustainability; Health, Productivity.

1. INTRODUCTION

The International Lighting Commission (in French, CIE) and the Illuminating Engineering Society (IES) of North America, are nonprofit organization that develop and publish standards on the fundamentals of light and lighting. Recently (2018), the CIE released a position statement on non-visual effects of light, entitled "Recommending Proper Light at the Proper Time", in which it is recognized that much research has been done but still more research is necessary as to this field, which links multidisciplinary efforts from psychology, biology, engineering, and architecture, just to name the more involved areas. Then, CIE issued an international standard, CIE S 026:2018, that defines a system for metrology of optical radiation for light-induced responses that can be elicited by intrinsically photosensitive Retinal Ganglion Cells (ipRGCs), containing the photopigment melanopsin.

Before talking about these cells, we must know that light is defined in the Lighting Handbook of the Illuminating Engineering Society of North America (Rea, 2000) as radiant energy that is capable of exciting the retina and producing a visual sensation. The optical radiation spectrum is divided into the following components: UV, 100 to 380 nm; visible, 380-780 nm; and IR, 780 nm to 1 mm. The UV-region of the electromagnetic spectrum was subdivided by the CIE into UV-C (100-280 nm), UV-B (280 to 315 nm) and UV-A (315-380 nm), and the IR-region has been divided into three bands, IR-A (780 to 1400 nm), IR-B (1400 to 3000 nm), and IR-C (3000 nm to 1 mm). Then, light is a visible form of electromagnetic radiation, bordered in the spectrum by ultraviolet radiation at shorter wavelengths and infrared at larger wavelengths. This visible radiation occupies the wavelength region between 380 and 780 nm, which produces the perception of violet 380-436; blue 436-495; green 495-566; yellow 566-589; orange 589-627; red 627-780.

Our eyes can detect this optical visible radiation for both: image-formation or vision, and for non-visual or circadian responses. The circadian effect of light means that light has an acute suppressive effect on the secretion of a circadian neurohormone called melatonin. How it does? The retino-hypothalamic tract (RHT) projects to the suprachiasmatic nucleus (SCN) in the hypothalamus, which is the principal circadian pacemaker in mammals. Neural projections from the suprachiasmatic nucleus travel to many diverse control centres in the nervous system including other areas of the hypothalamus as well as the thalamus, midbrain, brain stem, and spinal cord. One multisynaptic pathway that carries nonvisual photic information extends from the suprachiasmatic nucleus to the pineal gland (situated deep in the brain), with connections being made sequentially in the paraventricular hypothalamus, the upper thoracic intermediolateral cell column, and the superior cervical ganglion (Golombek & Ralph, 1996). Cycles of light and darkness relayed by the retina entrain suprachiasmatic nucleus neural activity, which in turn entrains the rhythmic production and secretion of melatonin from the pineal gland ganglion. To date, the most studied light-reactive hormones are melatonin and cortisol, whose patterns of secretion behave in a complementary way, being high levels of melatonin and low levels of cortisol secreted during night-time and high levels of cortisol and low levels of melatonin secreted during daytime (Tonello, 2001).

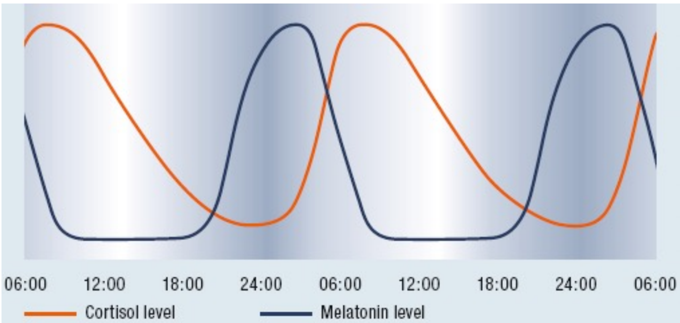

Figure 1. *Melatonin and cortisol pattern of secretion throughout the day (taken from licht.de 19).*

The action spectrum curves are different for the visual and non-visual systems; for the former the visual peak efficiency lies in the yellow–green wavelength region, while the maximum biological sensitivity lies in the blue region of the electromagnetic spectrum (Van Bommel, 2004). Then, the circadian or inhibitory effects of light can be achieved with high levels of illumination or with radiation in the shorter visible wavelengths. The sensitivity peak of the circadian and neuroendocrine systems has been shown to be in the blue-green portion of the spectrum (446-480nm). This finding is very important in terms of sustainability or energy efficiency since the biological effects can be obtained without the need to increase the lamp intensity. For instance, the cool white light-emitting diode (LED) produces significant light output at this visible short-wavelength. At this point, light distribution is also relevant, since the sensitivity of melanopsin-containing ganglion cells is higher in the lower half of the retina and can produce greater suppression of melatonin than the upper half, for the same light exposure. That´s why to obtain this type of responses is better the use of vertical measurement plane rather than the horizontal plane.

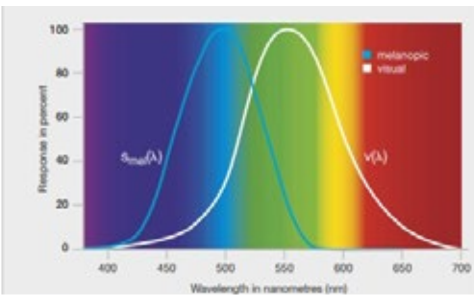

Figure 2. *Visual and Non-visual spectral sensitivities (taken from licht.de19).*

According to the CIE, for non-visual effects of light, the relative contribution of each individual photoreceptor can vary depending on the specific response and upon light exposure properties such as intensity, spectrum, duration, timing, prior light history, and sleep deprivation state of the individual. The workplace lighting design was almost always focused on visual performance, and due to energy saving requirements, also oriented towards increasing localized lighting, and the surrounding lighting is not considered. Thus, demands are usually satisfied by horizontal illuminance. On the contrary, for the circadian system, which is stimulated through the intrinsically photoreceptive ganglion cells, the lighting level of vertical surfaces such as walls and ceiling is especially relevant.

According to the CIE, the manipulation of melanopsin-based photoreception to get non-visual responses means:

- A high melanopic EDI during the day is usually supportive for alertness, the circadian rhythm and a good night's sleep.

- A low melanopic EDI in the evening and at night facilitates sleep initiation and consolidation.

The Melanopic EDI (Equivalent Daylight Illuminance) is a lighting dose with circadian purpose, which recommends a minimum of 250 lux during daytime (preferably from daylight), and a maximum of 10 lx in the afternoon (close to bedtime), and 1 lx at night (preferably under complete darkness).

As to the spectrum, we must try to avoid the shorter wavelengths during the evening in order to minimize ipRGC activity or keep retinal irradiance as low as possible.

In 2006, Figueiro and others suggested that if you want to be sure that you are receiving an alternating cycle of light and dark to entrain the circadian system, the light should consist of at least thirty lx for thirty minutes of white light, and dark should be low enough to take the visual system into the scotopic range.
You must know that all the circadian metrics developed to account for psycho-physiological effects of light use models with a peak sensitivity in the blue region of the visible spectrum at 490nm.

Based on the models of Gall and Rea, some metrics were developed. For instance, the Circadian Stimulus Calculator to evaluate the percent melatonin suppression expressed in terms of circadian stimulus (CS), being 0 when light does not cause any inhibition of melatonin in the blood) and 0,7 (when light inhibits the maximum level of melatonin).

Optical radiation has been used to treat skin diseases, hyperbilirubinemia, for vitamin D production, as well as for germicidal purposes (Di Laura, 2011).

Specifically, light is used clinically to treat the circadian - melatonic disbalance in seasonal depression or SAD, sleep disorders, to restore the sleep/wake cycle in people with Alzheimer and hospitalized patients in Intensive Care Units. But also, light can have a broader, non-clinical application for disorders such as shift work and jet lag, by means of behavioral strategies in the use of ambient light and darkness, as well as oral melatonin intake.

Currently, the climate crisis demands efforts from all areas of knowledge. The lighting field has contributed with the development of efficient lighting technologies such as the light emitting diodes (LEDs), and the design of sustainable buildings by means of the combination of daylight (as much as possible) and artificial lighting (of the best possible quality).

Our efforts as environmental psychologist who work in this field, consist in the study of behavioral changes for the better use of energy and the environmental conservation in general.

The Proper Light at the Proper Time means the translation of scientific evidence in the field of lighting into recommendations for a healthy daily pattern of light exposure, considering at the same time efficient light sources and design. And this concept is close related to the key terms of this symposium: Sustainability - Covid and Post-Covid times- Climate change- Energy conservation and energy transition- Challenges and opportunities.

Let's see how lighting research can contribute to pandemic and post-pandemic requirements. The term sustainable design in lighting implies:

The intelligent combination of artificial and natural light (in fact, the term biophilic design aims to reconnect users with the natural environment by means of the presence of green elements indoors).

And the use of efficient technologies such as LEDs as well as lighting controls. Lighting control requires luminaires that are dimmable. Daylight-dependent lighting control can reduce energy consumption by as much as 35 percent. Combined with timers and presence sensors, economies of 55 percent or more are possible (Licht, 2019).

The term healthy lighting implies not only level and spectrum of light, it is also related to behavioral strategies like:

The recommendation of spending adequate time outdoors during the day for a better health and well-being. Half an hour is recommended in adults and 2 hours outside is recommended in children to avoid myopia. Or a good quality of indoor lighting.

On the other hand, the exposure to daylight will help counteract the overexposure we have to artificial lighting, since LED was proven that it can delay or advance the circadian clock (Ticleanu & Littlefair, 2015). Then, the more we expose ourselves to daylight, the more melatonin we will secrete at night, and we saw this is important to get a deep sleep, which allows the recovery of the body and the activation of the immune-defensive system.

Since human evolution was shaped by natural light, it is also important to consider that a sustainable and healthy lighting practice involves the support of bright days and dark nights, to avoid circadian disruption. That´s why is very important to reduce the use of display screens after sunset, especially close to bedtime.

The WELL Building Standard for Light (launched in 2014) provides illumination guidelines that are aimed to minimize disruption to the body's circadian system, enhance productivity, support good sleep quality and provide appropriate visual acuity where needed.

Currently, everybody realized that hybrid modalities for communication will remain for a long period of time, and this implies the reshape of our home alongside a comfortable and versatile lighting of our workspace considering both its visual and non-visual effects. For instance, the vertical lighting, which is important for circadian purposes, is also required for videoconferencing for people's faces appearance. According to the CIE "integrative lighting" is the official term for lighting that is specifically intended to integrate visual and non-visual effects, producing physiological and psychological effects on humans.

Then, a good lighting installation must consider three dimensions: the visual, emotional and biological effects – and its energy-efficiency at the same time. Even more, in order to understand the potential risk to human health, it is necessary to characterize the light stimulus in terms of its physical properties: spectrum- intensity- duration- spatial distribution- timing- and quantification of the effective irradiance for each photoreceptor independently, to later be able to relate them to specific measurable psycho-biological responses such as melatonin and cortisol secretion, heart rate, brain activation, pupil constriction, performance, subjective alertness (Lucas et al, 2014).

2. STUDY

As an example of this approach, I will show you a study we have run on office lighting with different spectrum and light level (Tonello et al, 2019). I told you that the visual effects of lighting are mostly related to visual performance, while its nonvisual or psychobiological effects involve health and well-being. Then, in this study, a holistic approach comprising visual, emotional and biological dimensions was used to assess the lighting conditions that could favor productivity and well-being, by means of the identification of congruent relationships between objective and subjective measurements in response to light stimuli. The former included analyses of melatonin and cortisol, and the latter were psychological instruments for measuring transitory mood, somnolence, and visual comfort. In formulating the operational hypotheses, we assumed that lighting variations in terms of spectra and level during exposures of moderate duration will affect relevant psychobiological correlates. A secondary aim was to test the importance of co-variables such as the individuals' previous exposure to daylight (photic history), and their psychological profile in terms of personality type, perceived stress, and emotional state.

2.1. Set up and photometry

The laboratory set up consisted of two sets identically furnished, lacked windows, soundproof and temperature controlled. The lighting system consisted of two luminaires for each set: one located over the desk and the other was directed to the front wall. The first luminaire, with aluminum reflectors and open louvers, provided the general lighting by means of three compact fluorescent lamps of 36 W covered by a plastic diffuser. The other was a wall-washing luminaire with three tubes containing LEDs of 20 W, 21 W and 24W aimed at the wall in front of the subject. Both types of lighting, compact fluorescent lamps and LEDs, have Correlated Color Temperatures (CCT) of either 3000 K or 4000 K. They were selected because of their common use in office lighting in Argentina.

Figure 3. *The lab setup: the warm (3000 K) and cool (4000) CCT at the higher level (front wall light ON).*

The objective measures comprised photometric measurements such as Illuminance and Luminance levels, the spectral power distribution of each light sources as well as the spectral power distribution received at the cornea of the participants was also recorded to calculate the melanopic lux, as well as the Circadian Stimulus.

Table 1. Average Illuminances (E) and Luminances (L) on desk and walls in the two sets at different CCTs.

Light levels	Surfaces	3000 K			4000 K		
		L (cd/m^2)	E (lx)	Melanopic illuminance (melanopic-lux)	L (cd/m^2)	E (lx)	Melanopic illuminance (melanopic-lux)
Front wall ON (higher level)	Front wall	271	923	7.12	270	900	8.86
	Right wall	172	560		183	588	
	Left wall	177	600		178	585	
	Desktop	146	796		155	800	
	Paper	170			170		
	Screen	117			117		
Front wall OFF (lower level)	Front wall	70	176	1.78	73	196	2.36
	Right wall	80	300		85	305	
	Left wall	65	297		74	300	
	Desktop	68	440		67	460	
	Paper	90			90		

2.2. Hormones

Another objective measurement was the Melatonin and Cortisol sampling. In this study, for melatonin detection, the collection included two samples of urine. To identify the nocturnal pattern of secretion, a urine sample was collected at home, over 12 hours. A second sample of urine was collected at the laboratory. As to cortisol, it was collected in saliva six times: at 11 pm the night before the experiment, at 07:00 in the morning of the experiment, two samples during the experiment in response to changes in light level, and two samples after the experiment: at 5 and 11 pm. Participants were screened to rule out severe vision disabilities, infections, extreme chronotypes and endocrinology disturbances.

2.3. Subjective measures

Subjective measures comprised two psychological tests: the Scale for Mood Assessment and the Epworth Sleepiness Scale. The interior lighting quality was assessed by means of a questionnaire containing rating scales to estimate the impact of lighting on the appearance of the space in terms of unpleasant–pleasant, weak–strong, cold–warm, natural–unnatural, glaring–no glaring and soft–hard. The visibility condition (readability) was also measured ranging from very poor to very well. Visual discomfort had to be reported as experienced at the end of the experiment by means of a list of symptoms related to tears, visual fatigue, dryness, blurred vision, and headache. All these aspects were computed as indices which revealed Cronbach's reliability between moderate and high. The Photic history, or the individuals' previous exposure to daylight, as well as their sleep hours during the working week and at weekends were also investigated. Besides, complementary measures as co-variables were also carried out in order to investigate to what extent the impact of workplace lighting on the selected psychobiological outcomes would be mediated by the psychological profile of the participants. This construct was composed of tests of personality type, emotional state, and perceived stress.

2.4. Procedure

This study was a controlled experiment with a repeated measures design. A total of 56 evaluations were performed by seven participants, four males and three females with a mean age of 30 years. Each participant was randomly exposed to the four experimental conditions (two light levels and two spectra), during a period of two consecutive weeks in November (summer) and July (winter). In all, each participant attended eight sessions, at the same time of the day, from 09:00 to 13:00 hours. Each session lasted 1.5 hours and covered the exposure to one spectrum and one light level. The same procedure was followed the next week but under another spectrum. Task: Computers were used to fill in the psychological tests and the various questionnaires. For the performance task itself, both compute and paper were used since the task consisted of comparisons and error corrections between lists of numbers and letters into which errors had been randomly entered.

2.5. Results

Our results showed that the color temperature of 4000 K rendered most of the strong effects as to inter and intra correlations among psychobiological responses. The visual metrics in terms of illuminance and luminance were kept constant across the different experimental conditions while the non-visual metrics in terms of Circadian Stimulus and melanopic illuminance were higher for 4000 K.

Lighting appraisal: The lighting quality differentials used to rate the appearance of the experimental spaces have clearly discriminated the selected color temperature of 3000 K and 4000 K as warm and cool, respectively. The warm lighting was rated as pleasant and natural, while the cool lighting was rated as strong, and neither of them was rated as glaring. In this regard, the influence of the light level was important for various purposes, by accentuating the warmness and coolness properties, and for visibility, which improved at the lower light level under the cool lighting and at the higher light level under the warm lighting. This last finding may be explained by the spectral irradiance measurements that characterized the total light spectrum where the observer was immersed. That is, the LED system used at the higher light level expanded the blue component from 415 nm up to 480 nm even in the color temperature of 3000 K. We saw that Melanopsin, the photopigment of the ipRGCs, is particularly sensitive to blue light (wavelengths of 460–480 nm), and in addition to being involved in non-image-forming processes, it also plays a role in visual functions.

Melatonin and Cortisol: Since the experiments were carried out during the morning, melatonin was taken as a positive control and cortisol became a more reliable indicator to test the hypotheses. In this study, the expected complementary behavior of melatonin and cortisol was confirmed. The comparison between seasonal and experimental melatonin responses showed that those individuals more sensitive to seasonal variation showed greater sensitivity to the different experimental lighting conditions as well. Thus, those subjects who did not display the expected seasonal variation showed less variability to the experimental stimulus. On the other hand, and despite the small sample, the results also suggest that low melatonin secretors might be less sensitive to the experimental lighting stimulus. Cortisol measurements covered the 24-hour cycle by means of the six measurements. A statistically significant difference was found in winter between the 11 pm before and after the experiment, when participants were exposed to 4000 K.

Co-variables: The psychological profile of the individuals was a construct developed to better understand the dynamic of the assessment since their reaction tendencies might act as mediators. Among the tests selected to characterize the psychological profile of the individuals', perceived stress was the most reliable feature. Also, the higher light level improved mood, which was mediated by a relaxed personality such as type B. According to Stephenson, quality of mood tends to reflect the level of alertness, so, as sleepiness increases, quality of mood declines and sleepiness impairs concentration and memory, which further negatively impacts performance and well-being. Participants of this study showed a positive mood throughout the experiment, nevertheless, mood was affected significantly by cortisol and perceived stress, thus, an increased cortisol concentration improved mood while the increased perception of stress worsened mood. Cortisol was a strong predictor of transitory mood, and low values of cortisol were somewhat associated with more somnolence. Conversely, an increase in melatonin affected mood negatively, and correlations showed that, under the 4000 K color temperature, the higher the melatonin level, the lower the visibility to perform the task. Then, it can be inferred that the transitory mood of persons prone to stress might be affected by the exposure to a lighting of 4000 K and a level of 800 lx (horizontally) and 900 lx (vertically) with a melanopic illuminance of 8.86 lx.

3. CONCLUSION

In conclusion, despite the differences between the two sets in terms of Circadian Stimulus and melanopic illuminance, none of the tested lighting conditions have affected hormonal secretion in acute suppressive ways, maybe due to the limited exposure time and the range of spectra used. The exposure to each color temperature lasted almost four hours while the combination color plus light level lasted for 1.5 hours. Since one of the aims was to investigate transitory mood, the stay at each office set should have been moderate so that changes in mood are due to the experimental stimuli and not to feelings of confinement. Notwithstanding, statistically significant indirect effects were identified in the comparison of these apparently close temperatures. As to symptoms of visual discomfort that had to be reported at the end of each experimental session, the most frequent was ocular fatigue and blurred vision, under 4000 K, and perceived stress significantly predicted the number of symptoms. So, the perception of being a stressful person could have facilitated the experience of visual discomfort.

To finish, in line with what we saw, this study has identified that 4000 K lighting has the potential to provoke alertness or less somnolence, and therefore improved mood and visibility, but it was experienced as less comfortable. On the other hand, 3000 K lighting was better for the appraisal of the space, and its improvement on visibility seemed to be related to the higher light level, which was provided by the LED system. Lighting from LEDs can increase or decrease the CCT depending on the phosphors' properties. Both CCTs had a lot of spectral content in the blue area, this contribution being more noticeable in the set lit by 4000 K. Thus, this CCT should be able to modulate certain cognitive functions.

A contribution from psychology to lighting practice may be the consideration of the individuals' psychological profile, since it was suggested that this factor might explain the vulnerability to light found in many SAD studies. The psychological tests selected to characterize the psychological profile worked well in relation to the mediator role predicted in the hypotheses.

REFERENCES

Commission internationale de l'éclairage. (2018). Cie system for metrology of optical radiation for iprgc.

DiLaura, D.L., Houser, K.W., Mistrick, R.G., Steffy, G.R. (Eds). (2011). *The lighting handbook: Reference and application*, 10th ed. New York, USA: Illuminating Engineering Society.

Figueiro, M.G., Rea, M.S., Bullough, J.D. (2006). Does architectural lighting contribute to breast cancer? *Journal of Carcinogenesis*, 5, 20-32 Influenced responses to light (026/e:2018). doi: 10.25039/s026.2018

Licht.wissen (2019). *Impact of Light on Human Beings*. Recuperado de http://www.licht.de/en

Lucas, R.J., Peirson, S.N., Berson, D.M., Brown, T.M., Cooper, H.M., Czeisle,r C.A., …. Brainard, G.C. (2014). Measuring and using light in the melanopsin age. *Trends in Neurosciences*, 37, 1-9.

Rea, M. S. (Ed). (2000). Lighting Handbook: Reference and Application, 9th edn. New York, USA:Illuminating Engineering Society of North America.[3] Golombek, D. and Ralph, M. (1996). Let there be light: Signal transduction in a mammalian circadian system. *Brazilian Journal of Medical and Biological Research*, 29 (1), 131-140.

The WELL Building Standard®. (2014). Retrieved from https://www.wellcertified.com/
Ticleanu, C., Littlefair, P. (2015). A summary of LED lighting impacts on health. *International Journal of Sustainable Lighting*, 1, 5-11.

Tonello, G. (2001). Lighting, Mood, and Seasonal Fatigue in Northern Argentina. Comparison to Countries Close to and Further from the Equator. Doctoral thesis, Paper III, Lund Institute of Technology, Lund University, Lund, Sweden.

Tonello, G., Hernández de Borsetti, N., Borsetti, H., Tereschuk, M.L. y López Zigarán, S. (2019). Perceived well-being and light-reactive hormones. *Lighting Res. Technol*, 51, 184-205.

Van Bommel, W. (2005). Visual, Biological and Emotional Aspects of Lighting: recent new findings and their Meaning for Lighting practice. *Leukos*, 2 (1), 7-11.