

5^o CONGRESSO
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SOBRE
AMBIÊNCIAS

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SENSORY EXPLORATIONS

AMBIANCES IN A CHANGING WORLD

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Edited by

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**SENSORY
EXPLORATIONS**
AMBIANCES IN A CHANGING WORLD

Lisbon and Rio de Janeiro, October 8th to 11th.

Edited by

Mohammed Boubezari | Cristiane Rose Duarte | Ethel Pinheiro



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**LIGHT, COLOUR AND HUMAN BEINGS:
FUTURE CHALLENGES FOR A BETTER
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LUZ, COR E SERES HUMANOS: DESAFIOS FUTUROS PARA UM MELHOR DESIGN

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ABSTRACT

Lighting design involves product selection, arrangement, and system control. Despite its significant impact on human experiences, it is often reduced to aesthetic choices. Scientific literature highlights the influence of light on humans, frequently overlooked in favour of energy efficiency and visual performance. While efficiency and lighting practice remain essential, focusing solely on these aspects neglects broader well-being implications.

Professionals now recognise that photometry and calculations are insufficient; the perception of spaces, influenced by lighting distribution, is crucial. Lighting has evolved to support psychophysical well-being, incorporating technological advances and scientific research over the past twenty years.

The Human-Centric Lighting (HCL) approach enhances performance, attention, and sleep-wake cycles, particularly for night shift workers. However, the psychological response to light and colour remains underexplored. Understanding the emotional impact of light, influenced by various factors, is challenging but essential. Future research should document how light affects perception, cognition, and emotion to improve lighting design for individual well-being.

KEYWORDS: Light. Colour. Design. Psychology. Physiology.

RESUMO

O design de iluminação envolve a seleção de produtos, distribuição e controle dos sistemas. Apesar da importância do impacto da luz nos humanos, frequentemente esse aspecto é minimizado em relação à eficiência energética e resultados visuais. Focar apenas nesses aspectos negligencia uma abordagem mais ampla quanto ao bem-estar humano.

Profissionais da área reconhecem que só a parte técnica é insuficiente; a percepção dos espaços, influenciada pela distribuição da luz, é essencial, assim como incorporar avanços tecnológicos e pesquisas dos últimos vinte anos.

A iluminação centrada no ser humano melhora a performance, atenção e ciclos do sono, principalmente para quem trabalha em turnos noturnos. No entanto, a resposta psicológica à luz e à cor é pouco explorada. Entender o impacto emocional da luz, influenciado por diversos fatores, é desafiador, mas essencial. Pesquisas futuras devem documentar como a luz afeta percepção, cognição e emoção, com foco no bem-estar do indivíduo..

PALAVRAS CHAVE: Luz. Cor. Design. Psicologia. Fisiologia.

1. INTRODUCTION

The continuous succession of day and night is a simple phenomenon known by everyone, and it has been repeated every day since the dawn of time. In the millions of years that have seen human beings appear, survive and evolve into what we are today, the “simple” phenomenon of the succession of day and night has accompanied us. An event so common that no one questions it. Most people don’t even consider it, but this phenomenon has left indelible traces on our biology. The human being is made to “operate” during the day and “recharge” at night. Yet, since the discovery of fire, perhaps as many as 1.4 million years ago (Clark & Harris, 1985), our ancestors have used the flame to peer into the darkness, first to defend themselves and then, thanks to torches and all subsequent technologies, to lengthen the day, invading the hours of the night with “artificial” light (Schivelbusch, 1995).

The history of lighting design has gone back and forth, mainly remaining relegated to spaces occupied by nobles and wealthy merchants until the Industrial Revolution, when illuminating the spaces became necessary for productivity, and thanks to the improvement of gas lighting, light entered the homes of ordinary people in a widespread way (Chandler & Lacey, 1949). From here on, the race to improve technology and illuminating engineering seemed to be the only thing counted to give the population the best possible light.

But what is the “best possible light”? In the period of electrification of industries and domestic environments, the most desirable parameters were undoubtedly those relating to the lifespan of the lamps or their price, the luminous flux emitted and energy consumption. The main focus was to optimise the products by increasing their efficiency and directing the light onto functional areas, preventing energy waste where possible and containing glare for individuals. Lighting the spaces was the answer to the need to see clearly, uniformly, and without discomfort, maximising safety and, if possible, containing expenses. The approach to design was mainly engineering-like in the professional field and limited to the use of aesthetic lighting fixtures for the residential sector. The aspects related to the psychology of lighting, the human dimension, emotions and atmosphere were not part of the typical project of lighting systems. That light provokes emotions, however, is a common fact. Since the days of classical theatre (Marotti, 1974), it was common to use luminous deceptions to surprise the audience; in the first half of ‘900, cinema was marked by iconic masterpieces that had the construction of light on stage as the critical element of success. In these films, environments were recreated where light and shadow created tension and disquiet, as in Friedrich Wilhelm Murnau’s *Nosferatu* (1922) or left the viewer speechless, as in Fritz Lang’s *Metropolis* (1927). In Nuremberg in 1937, Albert Speer, architect of the Third Reich, designed the “Cathedral of Light”, a display of power for heads of state from all over the world, who commented admiringly on the incredible spectacle (Speer et al., 1969), unaware of the horrors that would soon be unleashed. Why was aesthetics not considered an essential parameter in architectural lighting design? Perhaps the limitations of the technology of the time,

or the fact that the world was recovering from the dramas of the Second World War, meant that lighting design did not consider people's mental and physical well-being until the fifties.

2. FROM OPTIMISED TO WHOLESOME

There are many important figures in the history of lighting design, but some are universally recognised as the true precursors of the modern way of illuminating spaces.

Probably the most known is the architect *Richard Kelly*, who, in 1950, highlighted the difficulty of selling lighting ideas, as at the time, the only things that were paid were the luminaires and not the lighting projects. Kelly then became the first “architectural lighting consultant” and postulated the three famous qualities of light in spaces, namely “*focal glow*” (light to highlight a detail), “*ambient luminescence*” (filling light to make a space brighter) and “*play of brilliance*” (bright sparks to create a glimpse of visual interest) (Kelly et al., 2010). The incredible prolificacy of his work and the numerous collaborations with the greatest architects of the time (IESNA, 2024) meant that people began to think about light in spaces not only quantitatively but also (and above all) qualitatively.

Architect *William Lam* is another figure we can point to as responsible for changing the direction of architectural lighting design. In 1959, Lam coined the saying “*Lighting by Design, not Engineering*”. His innovative approach to design involved collaboration between working groups from the very first steps of the project, integrating architecture, natural and artificial lighting and the building's systems. Lighting design intended not as a technical necessity at the end of the built space but as an element that contributed to shaping the environment from the very beginning of the design process. Its buildings were comfortable, functional and sustainable. In describing how a place should be illuminated, Lam identifies two groups of criteria, “*activity needs*” and “*biological needs*” (Lam, 1992). The activity needs can be summarised in good lighting engineering. Biological needs, on the other hand, represent the sum of all the psychological needs that proper lighting should solve in a place, regardless of its type. These multiple needs are divided into three large groups: *orientation*, *discernability* and *communication*. Orientation can be read in spatial terms as the ability to interpret *paths*, *entrances*, *exits* and *services*, also as a function of time, daylight conditions and what enters the space; a space without a clear orientation can be perceived as unnatural and oppressive. Discernability is the ability to read architecture clearly. The safety given by not having insufficiently lit areas, the structure of the surfaces and volumes highlighted by light and shadows, and the ease of identifying points of interest are all factors that allow you to experience the space in a safe and consequently relaxed way. Finally, communication is the ability to foster *social interaction*, where its extremes are seen as equally harmful (overcrowding and isolation); To encourage communication at the level of public life (multiple persons) or intimate (close and personal), and finally, the contemplation of elements (alone or in group).

3. SCIENTIFICALLY VALIDATED QUALITY OF LIGHT

As a result of Kelly and Lam's innovative approaches, many professionals paid renewed attention to lighting design. The driving force was undoubtedly the perception of space and the psychological sensations it conveyed. It was not until 1984 (Zehring et al., 1984) that researchers could demonstrate the functioning of the circadian cycle. This twenty-four-hour rhythm regulates the activity of our body through the production and inhibition of specific hormones. That light influenced mood, and the sleep-wake cycle had already been hypothesised for a long time; the concept of "*biorhythm*", now considered pseudoscience (Holley et al., 1981), had been used to try to predict the course of biology. Hall, Robash and Young's studies on the circadian cycle, which earned them the Nobel Prize in Physiology or Medicine in 2017 (Nobel Prize Press, 2017), laid the foundations of what is now called *Human-Centric Lighting (HCL)*.

This particular type of design approach takes into account factors related to the influence of light on the physiology of individuals. It can have numerous advantages if used correctly and in places where it makes sense. Light can affect our body in many ways: it can raise body temperature (Badia et al., 1991), increase heart rate (Cajochen et al., 2005), influence the activity of the cerebral cortex (Noguchi & Sakaguchi, 1999), improve the attention and performance of workers (Boyce et al., 1997; Monk et al., 1997), be used in the treatment of Seasonal Affective Disorder (SAD) (Lewy et al., 1982), helps in the regulation of sleep-wake cycles (Lack & Wright, 1993) also in the case of patients with Alzheimer's disease (Van Someren et al., 1997), and numerous other aspects.

In extreme summary, the principles of the HCL describe that inside the eye, in the retina, in addition to the most common photoreceptors (cones and rods), a type of photopigment has been identified that can translate light into electrical impulses and send them through a different path from that used for vision. This opsin (photosensitive protein) is called melanopsin and is primarily the first element that sets the light to influence the circadian cycle (Provencio et al., 1998). Light enters the eye and impacts the retina. Here, through a phenomenon called phototransduction, operated by melanopsin, light is converted into an electrical impulse and sent to the suprachiasmatic nucleus (SCN) located in the hypothalamus. The SCN is commonly known as the "biological clock" because it regulates circadian rhythms and, through the superior cervical ganglion, is connected to the pineal gland, which regulates melatonin in the blood. Melatonin is the hormone responsible for the propensity to fall asleep. It has also been discovered that the physiological response of the human being to light is not linear but is decidedly shifted towards shorter wavelengths, with a peak located at 480 nm, which corresponds to blue light (Brainard et al., 2001; Thapan et al., 2001). Interestingly, the channels influencing melatonin regulation are mostly Non-Image Forming (NIF) (McIntyre et al., 1989).

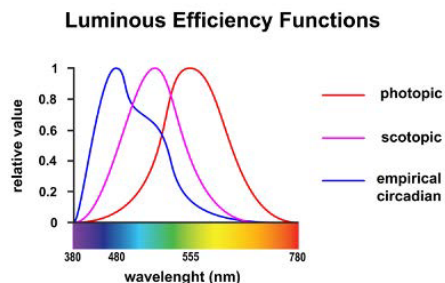


Figure 1: The three curves represent the efficiency of light in different aspects. The photopic curve is the human sensibility to colour in normal lighting conditions. The scotopic curve is the sensibility to colour in very dim light conditions. The empiric circadian curve (derived from the studies of Brainard and Thapan) shows the sensibility to the spectrum of our organism in relation to the physiological reaction to light. The last curve is unrelated to vision and starts with the phototransduction carried by the melanopsin (and not cones and rods like in the other two curves).

Over the last twenty years, these principles have led to the development of numerous lighting products based on the principles of HCL. Starting from the first approaches, which still used fluorescent light sources, such as the Sivra system by iGuzzini, Dynamic Lighting by Philips, and My White Light by Artemide, to name a few, we have arrived at the present day, after the revolution of LEDs and the so-called “digital light” which is connected, dynamic, controllable and highly flexible. The market today is teeming with lighting products designed for the well-being of individuals, to the point that sometimes these technologies are used in contexts where they are not needed. Nevertheless, a fundamental aspect of the interaction between light and human beings remains investigated in a less organic way than those commonly considered in the context of HCL.

4. PHYSIOLOGY VS PSYCHOLOGY

The premise of a research that is beginning at the *Laboratorio Luce* of the Department of Design of Politecnico di Milano (Italy), is that by questioning a large number of people during seminars, lectures and conferences, a discrepancy emerges relating to the perception of visual stimuli which, according to the principles of HCL, should be considered as “activators”. By asking subjects -who do not have expertise in the influence of light on the organism- which colour (when faced with a selection) they would define as “activating”, almost no one chooses blue; a clear majority of people are oriented towards yellow and orange. If you are asked to couple keywords with a stimulus, terms such as “cheerful”, “energising”, “love”, “anger”, and “energy” are always associated with colours such as yellow, orange and red. On the other side, blue is often associated with “sadness”, “serenity”, “cold”, “calm”, and “peace”, quite the opposite of what happens in the mechanism of interaction between light and physiology.

The first apparent thought is that the questions asked require a visual evaluation, while, as already mentioned, the mechanism that influences physiology is not related to vision but follows a different path. However, some studies (Hubbard et al., 2013;

Lockley et al., 2003) seem to confirm that cones (responsible for the perception of colour) also contribute to the mechanism of melatonin regulation. It isn't easy to think that a complex but balanced system, like our organism, possesses two mechanisms (one physiological and one psychological) that act so antagonistically. However, the emotional choice to associate a colour with an emotion does not seem to depend on physiological mechanisms.

Numerous studies in the field of psychology have dealt with colour preferences and the associations they arouse in individuals. The mechanism that leads subjects to prefer specific colours over others is not yet fully understood; however, one hypothesis (Humphrey, 1976) predicts that some colours are rooted in the biology of living beings and that they suggest atavistic reactions (the colour of flowers for pollinators, the vivid colours of certain poisonous amphibians for predators, etc.). Another study (Hurlbert & Ling, 2007) seems to experimentally validate the atavistic hypothesis, arguing that the evolution of the human visual system has favoured traits related to colours that are more advantageous to us in nature. The *Ecological Valence Theory (EVT)* (Palmer & Schloss, 2010) starts from the assumptions already described (which express results on an evolutionary-genetic scale) but also takes into account the experiences of individuals concerning certain visual stimuli. It, therefore, seems clear that there are associations between “pleasant” colours, such as blue/light blue (clear sky, clean water) and “unpleasant” colours, such as brown (associated with faeces and decomposition). Still, it is also true that the experience of individuals can have a profound impact on their personal preferences. The theory of *Color in Context* (Elliot & Maier, 2012) emphasises that the response to colour is involuntary; colour is not the stimulus itself but rather the basis of the percept that is created, triggering an appetitive or adverse response without the subject's awareness. However, the meaning attributed to colour can also be profoundly influenced by experience (social context, knowledge, folklore, rituals, art, fashion, etc.). Colour in context also highlights that not only does colour influence the three brain systems of affection, cognition and behaviour, but these systems are responsible for how we perceive colour. It would, therefore, appear that the observer's psychological state influences the perception of colour.

Over the years, numerous tests have been conducted to assess the extent to which colour could have a psychological influence on individuals; however, all these tests, conducted in the field of psychology, have always suffered from fundamental problems such as the lack of metrological rigour in the administration of the visual stimulus, the lack of consideration of environmental factors (like distance, or interference with background, etc.) and the reduced number of samples analysed. The practical applications of the results of these tests have not always produced the desired results; one example among many was the attempt to reduce prison violence by colouring cell walls pink (Schauss, 1979), which has proven over time to be not universally reproducible (Genschow et al., 2015).

5. COLOUR, EMOTION AND THE FUTURE OF LIGHTING DESIGN

Predicting the psychological effects of colour in lighting design is not as quantifiable as good lighting practice or HCL principles. However, this does not mean that coloured light is avoided or excluded. The massive presence of products on the market is an absolute indication of users' desire to use colours beyond the opinions, often excessively rigid, of the purists of the lighting project. In concerts, musicals, theatrical performances, fashion shows, installations, and clubs, coloured light is almost always present, and its purpose is always to leverage the observer's emotions. Anyone can buy, even on common e-commerce platforms at relatively low prices, lighting fixtures or "smart bulbs" that, when applied to standard luminaires, allow them to be transformed into systems capable of emitting dynamic coloured light by controlling them via smartphone or electronic personal assistant.

These products certainly do not have the primary purpose of effectively illuminating the space; instead, they use colour to provoke an emotional response. For this purpose, there are usually preset scenarios, which are based not on a quantitative, temporal or directional application of light (as in the case of HCL) but rather on the mimesis of idealised natural scenarios (tropical breeze, arctic sunrise, sunset in the savannah, northern lights, etc.). The idea is to recreate a natural percept, leveraging memories and emotions; however, this goal is pursued utterly empirically and without a scientific basis.

The challenge of this particular field would, therefore, be to understand whether designed lighting, based on the principles of HCL, can also perform the function of an *"emotional regulator"*, trying to understand whether there is any form of proportionality between the two mechanisms (physiological and psychological) (Siniscalco et al., 2022). The modification of intensity, directionality, and correlated colour temperature (warm-white / cool-white) has proven effects on physiology but has results – even adverse ones – that affect the psychology of individuals. Increasing the intensity and temperature of the colour (cold light) can improve a worker's level of attention and performance. Still, the perceived space may be less pleasant and, in the long term, affect mood, especially if the normal sleep-wake cycle is altered, as in the case of night shift workers (Bedrosian & Nelson, 2013). The presence of colour (and its change as a function of time) in the visual field of individuals has not been exhaustively investigated in the field of studies related to HCL, except to underline (Figueiro et al., 2004) that the principle of the chromatic opponent can also be applied in physiological mechanisms (Hering, 1964).

Does provoking a psychological response through colour in an individual's field of view affect the circadian cycle regulatory effect? Does emotionally mitigating (through colour) the stress induced by a visual stimulus that aims to inhibit melatonin production, preventing falling asleep, affect the physiological process? Given that light can provoke emotions, can it be used to induce controlled emotional states?

Being able to shed light on these questions could lead to a new way of approaching the lighting design of spaces, both professional ones with much more stringent performance requirements and residential ones, where it could simply improve the mood of the occupants. Current technologies allow great flexibility: in the production of dynamic lighting fixtures, where it is possible to control the intensity and chromaticity of the individual LED modules, where optics can be installed that allow accurate control of the luminous flux and in the presence of electronics allows IoT programming (in the future also prediction, thanks to generative AI (Kasanagottu et al., 2024)).

6. CONCLUSIONS

Extensive research in the scientific literature suggests that light and colour influence humans through two mechanisms, one psychological and one physiological, that seem to act separately, sometimes agonistically. This paper briefly presents the difference between these two mechanisms and asks questions about their possible interaction.

These questions are the starting point of research (in the initial phase) based on exposure to dynamic lighting systems (HCLs) and luminaires capable of producing coloured light, with subsequent psychological tests such as Self-Assessment Manikin (Bradley & Lang, 1994) and Panas scale (Watson et al., 1988).

Following these tests, the analysis of the results will aim to find relationships between the physiological response, well known and documented in the literature, and the psychological one, which, in many respects, is still to be investigated. If a relationship exists, it will be possible to draw up a series of guidelines to obtain lighting projects and lighting products that could perceptibly benefit individuals' well-being and mood, improving their performance when confronting activities commonly perceived as stressful.

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SENSORY EXPLORATIONS

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