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Conceptualization of color temperature scenario applied to quality lighting design.

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Abstract

Quality lighting is characterized by four major factors, one of them being the color temperature. When designed for elderly, this quality lighting can allow them to evolve within their environment safely, independently and above all comfort without having to focus on the effects of aging. This article aims to show the benefits of designing color temperature scenarios, made possible for example by dynamic LED lighting, thus contributing to the production of comfortable lighting and thus quality.

Keywords: *Color and Light Design; LED lighting; Elderly users; Visual comfort.*

Introduction

It seems natural to say that a good light is necessary for a good vision, thus allowing us to go about our daily activities. But let's start by defining what a good light is: a quality lighting. It is characterized in the first place by its implementation, its location within a defined local, considering then the ergorama (workstation or place of activity of the user), the panorama (wider area allowing the rest of the visual system), and the connections that take place between the two. These different elements then constitute the previously defined environment.

Quality lighting is also defined by the visual comfort it provides to its users through the lighting solution itself [1] [2]. If this is true for the average observer, this is especially so for elderly with a higher prevalence of visual impairment. After sixty years, more than one in two [3] would be visually impaired. These are called mild impairments, such as decreased sensitivity to low contrast, visual acuity or accommodation, to acute impairments caused by age-related diseases, such as AMD (Age-related Macular Degeneration) leading to a deterioration of central and peripheral vision, which can sometimes even lead to blindness [4]. In general, these impairments mainly impact daily practices (reading, writing, cooking, etc.) as well as movement. Habitat can become a source of disability and/or insecurity and discomfort [5].

That is why it is important for elderly to be able to move in an environment with quality lighting. It generates a suitable visual environment and allowing them to practice their daily activities. This contributes to their comfort without being limited to the consequences of natural aging. Indeed, not being able to maintain the habits of life and the daily routines can cause in the elderly a depressive state. This resentment is a reflection of the natural decrease of their abilities and a physical evolution beyond their control. The risk of falling also contributes to this resentment, and contributes greatly to the feeling of insecurity and loss of autonomy linked to an unsuitable environment [6][7]. The home must remain "the ordinary habitat, a place where the user can keep his physical and psychological markers, this is necessary for his well-aging" [8].

Changing the habitat therefore contributes to the prevention of the risks associated with these pathologies, which interferes in particular with the abilities and visual comfort of the elderly. To generate this adapted environment, and more particularly the visual comfort, it is important to identify the conditions required for this comfort [1]. We will talk about hygiene, performance and visual satisfaction. The visual performance relates to the levels of illumination as well as the color rendering (color rendering index and color temperature), with regard to the visual characteristics of the user, as regards visual hygiene. Visual satisfaction comes from users' perceptive sensations and from their subjective appreciation instead, having as a point of comparison natural lighting.

Take for example Table 1. taken from a lighting guide relating to the tables and values of the European standards, "Lighting of indoor workplaces", EN 12464-1 (June 2011) [9]. In particular, it provides minimum levels of illumination and color rendering, compared to an average observer, and recommending neutral white color temperatures between 3300K and 5000K. According to the standards in force, the obtaining of a comfortable visual environment is made possible thanks to the respect of these minimum values. However, it is necessary to consider the illumination and color temperature factors systemically.

Indeed, as demonstrated by Kruithof [10] in Figure 1., the relationship between illumination and color temperature impacts our visual comfort. It thus makes it possible, thanks to its diagram, a zone judged as comfortable when one observes a balance between illumination and color temperature. If the Kruithof diagram "allows us to avoid difficult situations" [1] and gives a reprint in light design, we mustn't forget the environmental factor related to the user and consider a more complex design model.

Table 1. Extract from the Zumtobel lighting guide for health facilities: health institution

	Lx	UGR_L	U_O	R_a
Staff room				
Service room	500	19	0,6	80
Staff relaxation room	300	19	0,6	80
Patient rooms				
General lighting (Ground)	100	19	0,4	80
Reading lights	300	19	0,7	80
Simple examinations	300	19	0,6	80
Examination and treatment	1000	19	0,7	90
Night lighting/surveillance	5	-	-	80
Bathroom and toilets for patients	200	22	0,4	80

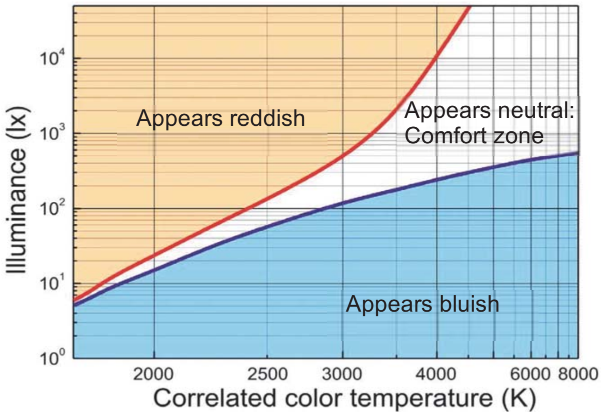

Figure 1. *Kruithof diagram that identifies whether lighting is judged to be comfortable based on its color temperature and light intensity.*

This feeling of comfort is therefore also played out in the margins of metric considerations. Indeed, this condition of visual comfort is also and above all closely related to natural light, judging then "a comfortable artificial light when it appears to us the same aspect as a daylight" [11]. This resemblance to natural light would then result in a light design that suggests the sun's course. For this, we need to simulate the natural color temperature changes that take place throughout the day, thus following the chromatic cycle of natural light, illustrated in Figure 2. Designing and choosing a dimmable lighting allows us to modulate light intensity and color temperature.

It would help to conserve natural light-related behaviors, such as falling asleep faster at sunset (in warm white light), or faster wake-up at sunrise neutral white) and showing increased efficiency during our activities when the sun is at its zenith (falling in a cold white light).

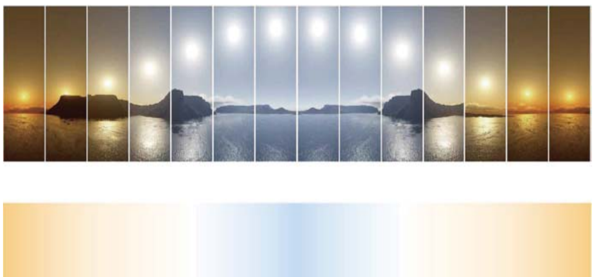

Figure 2. *Chromatic representation of the sun's course and its color temperatures.*

The color temperature plays a role in the apprehension of the environment and influences behavior. This is why in light design it is important to design reasoned lighting, in correlation with the built environment and the natural lighting. This is all the easier today thanks to the technological evolution of lighting solutions. LED lighting makes it possible to design dynamic scenarios adaptable to the desires and needs of everyone. The design of color temperature scenarios thus offers an optimal reading of the environment. Elderly users are no longer limited to the effects of aging. Thanks quality lighting, we convey the beneficial effects of light, including the natural regulation of the circadian cycle.

Indeed, exposure to natural light helps regulate the brain's chemistry and so our internal clock is the circadian cycle. But natural aging leads to a gradual deregulation of this cycle. That's why light is an effective and popular alternative to drugs [12].

Experimentation

To consider the design of these color temperature scenarios, we questioned the field of possibilities of LED lighting and its ability to propose a color temperature dynamic, relative to the daylight and its color temperatures. We therefore seek to theoretically question the capacity of such a dynamic to adapt to everyday uses and their evolutions. For this, we are interested in the Philips LED solution, “Hue White Ambiance”, for its accessibility in the domestic and connected lighting market, in adequacy with the theoretical questioning of the daily practices. We therefore seek to highlight its correspondence with the natural light color temperatures belonging to the family of white lights, observed in Figure 3. This color map allows to isolate the colors relative to natural color temperatures mainly observed.

To judge this ability to reproduce the natural light cycle, we assessed its photometric and radiometric conformity. We also took a photographic capture allowing a chromatic coding of the different lighting. We also tried to determine if the different temperature / color intensity combinations could be considered comfortable, thanks to a correlation with the Kruithof diagram.

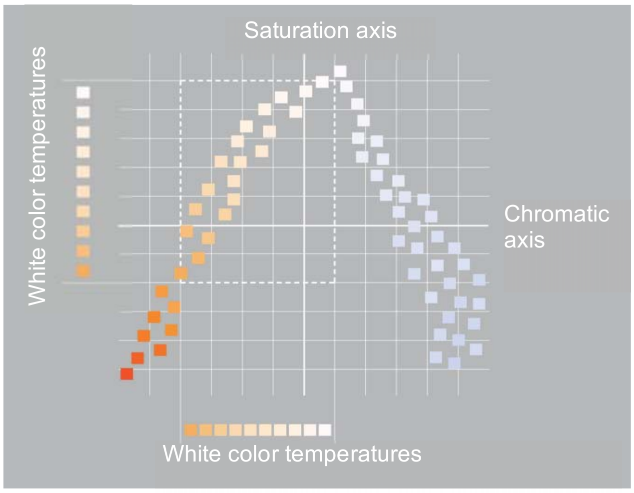

Figure 3. *Chromatic mapping representing the color temperatures relative to natural light and the sun's course. This mapping thus makes it possible to identify the so-called white color temperatures.*
The chromatic axis identifies the color temperature from red to blue, from the lowest temperature to the highest. The saturation axis represents the progressive chromatic desaturation of color temperatures to the whiteness of some.

Results

This dynamic lighting can produce four color temperatures, on average 2200K corresponding to the light of a candle, 2900K corresponding to sunrise or sunset, 4300K corresponding to the morning or afternoon sun, 6200K corresponding to a sun at zenith by clear sky, for a luminance going on average of 3800 cd·m-2 equivalent to the illumination of the morning or the evening, with 35000 cd·m-2 equivalent to the illumination from a clear sky to noon [13] [14] [15].

An application for a dedicated smartphone allows you to configure predefined or customized cycles, depending on our activities or the time of day, to create light sequences. The multiple shades, obtained in Figure 4. thanks to the different colors of temperature and levels of illumination, participate in the multiplication of combinatory, and open a vast field of possibilities in term of conception of luminous atmospheres. Table 2. expresses the resemblance between artificial lighting and daylight. To obtain these results we measured each possible illumination with a spectroradiometer. We have thus identified each of the corresponding spectra to establish the photometric and radiometric conformity. The photometric index being defined as the scalar product of the normalized vectors obtained as observed spectra weighted by the sensitivity function CIE1931 V (lambda). The radiometric index was computed as the dot product of the normalized spectra over the range 380-780 nm.

These results, also obtained during a previous study [16], show a remarkable level of photometric conformity (as perceived by human vision) and a radiometric conformity considered satisfactory because higher than 70% on average. The different variations make it possible to create singular rhythms that can be easily renewed.

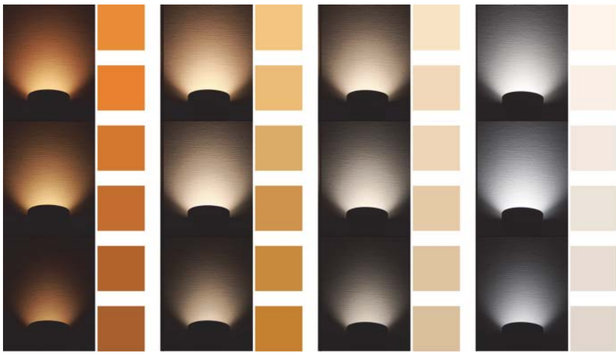

Figure 4. *Photographic capture and chromatic color-coding of "Hue White Ambiance" color temperatures and their evolution for the most representative levels of illumination, respectively: 2200K; 2900K; 4300K; 6200K, for 38000 cd·m-2, 35000 cd·m-2 and 15600 cd·m-2.*

Table 2. Metrics Characteristics of color temperatures

	CCT1	CCT2	CCT3	CCT4
Photometric conformity	99,3%	99,6%	99,6%	99,4%
Radiometric conformity	54%	69%	80%	83%
Average Color Temperature	2200K	2900K	4300K	6200K

If, indeed, the color temperatures have almost perfect photometric conformity with those of natural light, a color comparison on Figure 5. tells us that only certain shades correspond to the natural color temperatures. We observe a greater correspondence with the more neutral hues, excluding, on the contrary, all the shades of the hottest lighting. The chromatic sample of this artificial lighting thus represents the equivalent of a third of the color temperatures relating to natural light, while excluding the shades of the lowest color temperature. Moreover, if the averages corresponding to the four color temperatures, correlated with the three levels of illumination identified during the photographic capture are entered in the Kruitof diagram on Figure 6., we find that the two coldest color temperatures are considered comfortable with regard to the composition of the diagram. While the two hottest color temperatures are considered uncomfortable for these high levels of illumination. This is due to their respective heat, which according to the logic followed by this diagram, generate visual ambience too far away from the natural light scenes.

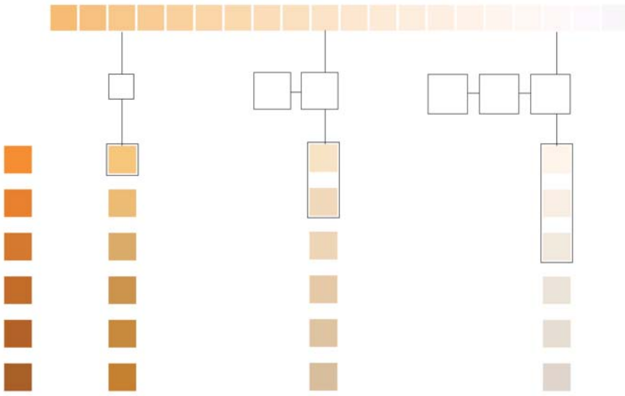

Figure 5. *Chromatic observation of the correspondence between "Hue White Ambiance" color temperatures and natural light.*

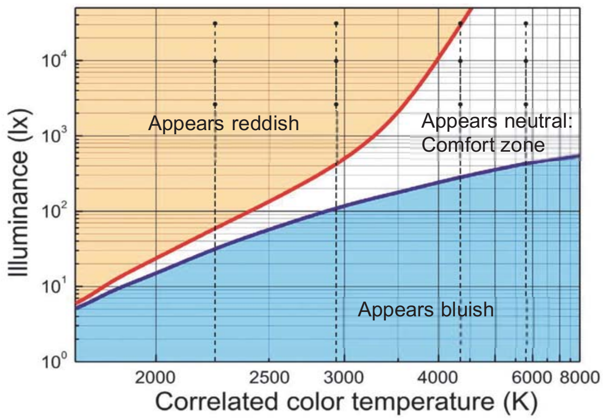

Figure 6. *Presentation of the "Hue White Ambiance" color temperature and light intensity couple, relating to the Kruithof diagram.*

Discussion

The study shows us that a flexible solution makes it possible to create color temperature scenarios according to the environment, desires and needs thanks to its ease of use. In addition, its color characteristics suggest the chromatic cycle of natural light. It is able to respond to the idea of comfort linked to this race of natural light and natural regulation of biological needs such as circadian rhythm, especially in the elderly, a consequence of natural aging.

The relationship between visual comfort and natural light is reinforced by the Kruithof diagram. It shows us that the color temperatures with the most chromatic similarities with the natural color temperatures appear in the zone considered comfortable with respect to the setting correlation between color temperature and illumination.

But we mustn't forget, however, that the chromatic appreciation of light is subjective and strictly personal, induced by factors such as age, the user's visual health, sex or place of life. Indeed, generally warm lights will be preferred in the countries of northern Europe, while colder lights will be used in the Maghreb countries [17]. Studies that have focused on the relationship between gender and light have also shown that women tend to prefer warm lights, unlike men who show signs of mood swings for a positive mood when the color temperatures vary for colder lights [18] [19]. In addition, there will be a preference for higher color temperatures and higher illumination in elderly age groups than in younger groups [20].

It is also important to remember that the appreciation of a color temperature depends on its environment and its context of activity. Indeed, color temperatures between 3000K and 5000K will be favored, and particularly preferred by the elderly, as was shown in the study of O'Connor [19], to allow an optimal discrimination of the environment, because they offer an excellent recognition of the colors and they also facilitate the visual adaptation when one passes of the one to the other [21] [22]. This first combination is of particular interest for a better understanding of the space for the elderly, thus making it easier for them to identify the obstacles and volumes of their environment, or when they pass from one environment to another.

Above these 5000K, one will choose the practice of activities requiring a certain concentration and this optimal discrimination of the environment here immediate as in the practice of writing or reading for example. Even colder lights can be used (up to 7000K) during group activity activities in common places and enjoying extended space or so-called technical parts. On the other hand, the use of color temperature below 3000K will be preferred for activities that are conducive to relaxation and even to falling asleep at a color temperature of around 2300K [23] [24].

Table 3. Simplified usage scenario of color temperatures applied to living spaces

2000K	3000K	4000K	5000K	6000K	7000K
Bedroom	Bathroom				
		Kitchen Dining Room			
	Corridor Vestibule				
			Office		
				Garage Cellar	

These different recommendations make it possible to establish scenarios of uses of these multiple color temperatures, according to the activities practiced. But it is important to pay attention to avoid the generalization of the same scenario, as for example the simplified scenario Table 3. Nuance this configuration will allow to modulate it according to additional criteria, besides the daily practices, as for example a possible visual impairment of the user or the multiple occupation of the same space by various users.

Not to mention its perpetual correlation with levels of lighting adapted to the situation, especially with regard to the contribution of natural light in the built environment.

Conclusion

Designing quality lighting induces the need to design a comfortable lighting, or at least judged as such by its users. A major consideration given to the choice of color temperatures then contributes to obtaining this comfort, considering here in particular the visual comfort, because of the strong physiological impact that it can have. The design of a mimetic model with natural light is able to bring major benefits, especially to the elderly, giving them for example a sense of security through a better apprehension of their environment, but also visual comfort and autonomy in their daily practices.

But it seems important to remember the singularity of each person, whether it is considered part of the population of the elderly, assets or children. It's therefore advisable to propose a design model and a flexible and dynamic lighting solution, in order to give users full autonomy to decide their scenarios, so that they fully respond to their habits or to the evolution their needs or simply their desires.

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Authors Biography

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Laurent Canale, PhD, MIEEE’12, SMIEEE’19, holds a Master and PhD focusing on High Frequencies Electronics and Optoelectronics from Limoges University, France, in 1998 and 2002. His main PhD work was in pulsed laser deposition of lithium niobate thin films for optical telecommunications. He is CNRS Research Engineer in LAPLACE Lab., "Light & Matter".

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