LEDMOTIVE

Turn on the future

Natural and dynamic lighting with spectral LED technology for HOSPITALS and HEALTH CARE applications

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1. Introduction

LEDMOTIVE offers an intelligent lighting system, versatile and with the highest quality through the combination of multiple LED channels, allowing to obtain **any light spectrum** in the visible range. This light can be adapted to people's needs, affecting both the visual and the **non-visual response**, to improve mood and wellness for a greater concentration, relaxation and a **faster recovery** for patients in health centers.

Several scientific studies demonstrate the **large impact that daylight has over the human biology** (i.e. suppression of the hormone melatonin, influence in our immune system, Vitamin-D generation, performance and mood, etc.). The biological impact varies depending on the type of illumination (intensity/spectrum, natural/artificial) and on exposure times.

The new spectral lighting system by LEDMOTIVE allows to reproduce natural daylight, including changes over the course of a day, with the highest visual quality and without resorting to very high illuminance (lux levels), which significantly improves the patient's comfort during prolonged hospitalizations. LEDMOTIVE lighting technology is easy to install and facilitates the recovery of critical patients **by synchronizing the circadian rhythms** while offering the **highest fidelity to daylight**. In this way, it induces a **greater arousal and improved orientation** during the day, guaranteeing a **good rest** over the night, which is a key factor known to **reduce delirium** in patients with long stay demands.

The lighting system **enables the complete removal of blue light** when necessary. The benefits of this are two-hold. First, it **avoids potential ocular hazards** associated to long exposures to blue light, and second, it **improves sleep patterns** and prepares the body for a good rest during the evening by avoiding the suppression of melatonin before bed time.

This makes it possible to have an illumination **tailored to the patients' needs**, aimed at providing the healthiest environment while at the same time making an **economic and environmental impact**.

The developed control software allows programming the luminaires to emit any light spectrum, so it is not necessary to modify the physical installation to change the lighting (spectral) design of the illuminated space.

Our software can be easily integrated with existing Building Management Systems (BMS) both with illumination **and signaling** purposes after a given alarm is raised (monitored emergency, noise, etc.).

"LEDMOTIVE allows to transfer the ***dynamism of daylight to health care environments,*** *situating the patients' health on top of the equation and providing an adequate atmosphere based on natural light"*

2. Scientific Evidence

2.1 Human Centric Lighting

LED technology is breaking into the lighting market thanks to its low consumption, high light output, long life and use of non-polluting materials. Given its great modulation capabilities, LEDMOTIVE has developed a disruptive technology to offer a light source with the **highest illumination quality**, far superior to the LED technologies that are currently available in the market. LEDMOTIVE offers a holistic solution in the lighting industry known as Human Centric Lighting (HCL), centered 100% around humans.

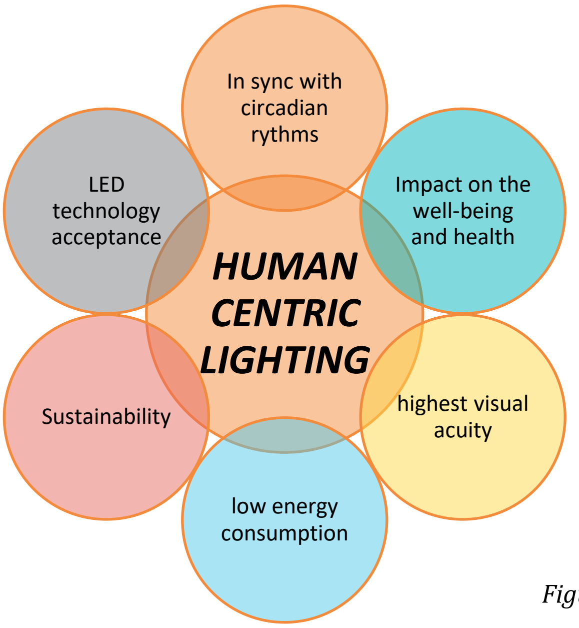

Figure 1. Human Centric Lighting

Daylight is the most natural light possible for human beings. We have evolved with it and our biology is governed by its daily cycle. But, what properties does this type of light have?

Sunlight is a radiation characterized by a Spectral Power Distribution (SPD) curve that resembles that of a Planckian radiator (Blackbody radiator or incandescent object):

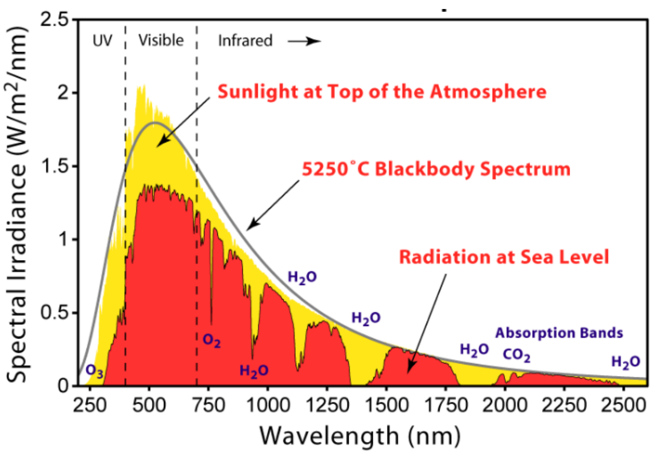

Figure 2. Sunlight vs Planck's radiation

The interaction of sunlight with the chemical elements present in the atmosphere (depending on the sun height from the horizon and light dispersion in the air) modifies the solar spectrum throughout the day observed from the earth. For instance, we observe a white light at noon but a more reddish light at sunset or dawn.

The **spectral composition of sunlight changes throughout the day and our biology has evolved to be adapted and respond to these changes**. Depending on the time of the day, our body prepares for different biological processes. But, **what makes the light spectrum so important?**

According to recent research, our eyes contain a new type of photoreceptor, different from the well-known cones and rods (the ones responsible for providing color and image formation, shaping the objects around us) whose information is processed in a different part of the brain. This new photoreceptor is termed intrinsically photosensitive Retinal Ganglion Cells (ip-RGC), and it has a unique spectral sensitivity that is **responsible for the non-visual path stimulation,** which has a major role on the synchronization of the **circadian rhythms**[1] in humans and many other mammals.

LEDMOTIVE offers a **dynamic and versatile illumination with the highest quality** through the combination of multiple LED channels to **re-create any light spectrum in the visible range**. This type of light can be adapted to people's needs influencing both the visual and non-visual pathways to improve a number of parameters such as arousal, concentration, mood, reaction times, or synchronization of the circadian rhythms to the 24h clock, which is a critical factor influencing our health, and is crucial in health care environments such as in **hospitals and ICU rooms**.

Color Coordinates (x,y), Correlated Color Temperature (CCT), Color Rendering Index (CRI) and illuminance (lux) are generic terms frequently used to describe light properties when illuminating a space. They work well to describe basic properties of light and professionals in the lighting industry are familiar with them. However, they are simplifications of a physical entity that contains much more information, including information that can be used to classify light as beneficial or detrimental to our biological condition; the spectrum of light. So, whenever there are physical and biological processes involved as a response of a **non-visual light stimulus**, it is necessary to speak in terms of the **spectrum of light used** or at least find the right indicators to evaluate the potential of a given light spectrum to impact a set of health outcomes.

Several scientific studies have shown that **the light spectrum can be optimized to change the state of alertness and mood** as a function of the time of the day and the task

[1] https://en.wikipedia.org/wiki/Intrinsically_photosensitive_retinal_ganglion_cells

being carried out. Biosensors detecting heart rate and body temperature can measure responses to changes in light, so that quantitative data can been measured to analyze the impact of light in humans.

Finally, it is well known that **blue light**[2] (embedded in most of the electronic devices containing LED as back-lighting illumination such as mobiles and tablets) may have a **harmful** effect on our health. Not only they can cause eye diseases resulting from prolonged exposure to blue or ultraviolet light, but also may cause disorders in our circadian cycle.

As an example, we cite several references in this field:

- Impact of light over the production of melatonin, the hormone that helps to fall asleep and regulates our circadian rhythms: [3], [4], [5], [6]
- Impact of light over mood and how circadian rhythms contribute to our health and well-being: [7], [8], [9], [10], [11], [12]

It's important to highlight that the **Medicine Nobel Laureate 2017** was awarded to the North Americans Jeffrey C. Hall, Michael Rosbash and Michael W. Young for their discoveries on the molecular mechanisms controlling the circadian rhythm.

The award-winners were able to explain how plants, animals and humans have adapted their biological rhythm to synchronize it with earth's rotation, known as the **biological clock**. This is applicable to the jet-lag produced by transoceanic flights as well as the chlorophyll function of plants. The clock adapts the physiology drastically to the circadian rhythm, regulating hormone levels, body temperature or metabolism.

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[2] http://www.pointsdevue.com/article/blue-light-scientific-evidence-patient-care

[3] Santhi N, Thorne HC, van der Veen DR, Johnsen S, Mills SL, Hommes V, Schlangen LJM, Archer SN, Dijk DJ (2011) *The spectral composition of evening light and individual differences in the suppression of melatonin and delay of sleep in humans*. J Pineal Res 53: 47-59. 10.1111/j.1600-079X.2011.00970

[4] Mishima K, Okawa M, Shimizu T, Hishikawa Y (2001) *Diminished melatonin secretion in the elderly caused by insufficient environmental illumination*. J Clin Endocrinol Metab 86: 129-134

[5] Czeisler CA, Shanahan TL, Klerman EB, Martens H, Brotman DJ, Emens JS, Klein T, Rizzo JF, III (1995) *Suppression of melatonin secretion in some blind patients by exposure to bright light*. N Engl J Med 332:6-11

[6] J. M. Zeitzer, D. J. Dijk, R. Kronauer, E. Brown, and C. Czeisler. *Sensitivity of the human circadian pacemaker to nocturnal light: melatonin phase resetting and suppression.* J. Physiol 526 Pt 3:695-702, 2000

[7] T. Partonen and J. Lonnqvist. *Bright light improves vitality and alleviates distress in healthy people*. J. Affect.Disord. 57 (1-3):55-61, 2000

[8] G. W. Lambert, C. Reid, D. M. Kaye, G. L. Jennings, and M. D. Esler. *Effect of sunlight and season on serotonin turnover in the brain*. Lancet 360 (9348):1840-1842, 2002

[9] M. Aan Het Rot, D. S. Moskowitz, and S. N. Young. *Exposure to bright light is associated with positive social interaction and good mood over short time periods: A naturalistic study in mildly seasonal people.* J Psychiatr. Res, 2007

[10] A. Tuunainen, D. F. Kripke, and T. Endo. *Light therapy for non-seasonal depression*. Cochrane. Database.Syst.Rev. (2): CD004050, 2004

[11] R. N. Golden, B. N. Gaynes, R. D. Ekstrom, R. M. Hamer, F. M. Jacobsen, T. Suppes, K. L. Wisner, and C. B. Nemeroff. *The efficacy of light therapy in the treatment of mood disorders: a review and meta-analysis of the evidence*. Am.J. Psychiatry 162 (4):656-662, 2005

[12] A. Wirz-Justice, F. Benedetti, and M. Terman. *Chronotherapeutics for Affective Disorders: A Clinician's Manual for Light and Wake Therapy*, Basel:Karger, 2009

2.2 Illumination for the circadian rhythm

The metric Circadian Stimulus (CS), developed by researchers from the *Lighting Research Center*[13] is used to assess the effectiveness of a light source for stimulating the circadian system by measuring the suppression of the body's production of melatonin resulting from exposure to that source.

The following figure shows the absolute sensitivity of the human circadian system plotted as a function of light level, where the spectral power distributions (SPD) of various light sources used in previous studies are weighted according to circadian light (CL_A), as seen on the x-axis. The y-axis on the right, labeled circadian stimulus (CS), is scaled to be proportional to the y-axis on the left, which shows the amount of melatonin suppressed after exposing the retina for 1 hour, ranging from 0.1 (no measurable suppression) to a maximum of 0.7 (70% suppression).

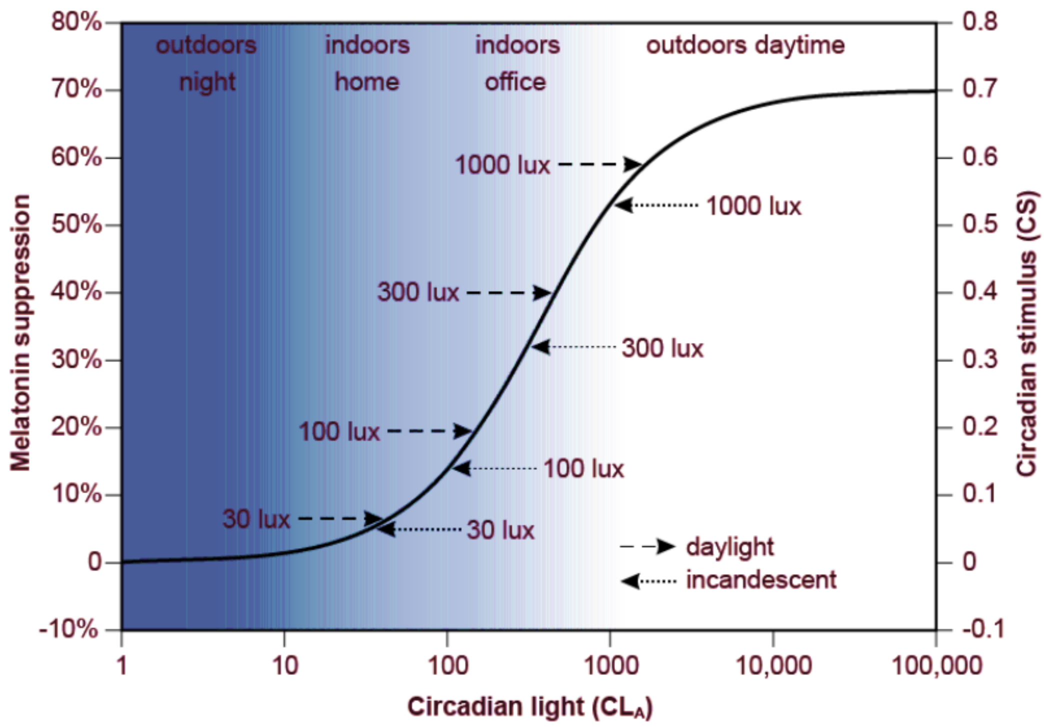

Figure 3. Sensitivity of a human circadian system

Several previous studies employing the CS metric and involving diverse populations have shown that exposure to high levels of circadian-effective light (CS > 0.30) during the day, particularly in the morning, is associated with **improved sleep quality, mood**, and circadian entrainment as well as **greater subjective and objective alertness**. People

[13] http://www.lrc.rpi.edu/

who receive morning CS ≤ 0.10, on the other hand, are unlikely to be well synchronized to the natural day–night cycle and the various schedules that are associated with everyday life[14].

Taking the example of an Intense Care Unit (ICU), a static lighting system using a light source with a CCT of 4000K would require an average illuminance of 400 lux to reach a CS target of 0.3. A light source with a CCT of 5000 K able to provide 300 lux to the eye level (not direct light) would deliver a CS=0.3 while another light source with shorter wavelengths (for instance high content of 460 nm) it would only require on average 50 lux to reach a CS=0.4. In this sense, the use of a spectral adjustment system offers much more flexibility and prevents potentially harmful retinal exposures[15].

Therefore, when we talk about a **spectral light control system**, such as the LEDMOTIVE system, the **impact on the circadian rhythm stimulus (CS)** is **maximized**, obtaining much more beneficial results for the same (or even lower) levels of photopic illumination.

[14] http://www.lrc.rpi.edu/
[15] http://lightingpatternsforhealthybuildings.org/content/20

2.3 Scientific results using the LEDMOTIVE module

Below are some of the **scientific results after using LEDMOTIVE LED modules** and their favorable effects to **control the circadian rhythms** in humans during the **Hi-LED Project** (http://www.hi-led.eu) **funded by the European Commission with a budget of 5M€**:

- **Institute of Neuroscience** (**INN**), research center linked to the Newcastle University. The INN has been using during the whole project for 3 years[16] the LED modules manufactured by LEDMOTIVE. They have **demonstrated, using our multispectral light source, that the alertness levels, performance and mood can be adjusted depending on the time of the day and task requirements**. Through a series of wireless biosensors, it has been possible to monitor the physiological state of people (such as melatonin levels in saliva, heart rate, cardiac variability and body temperature) to find the light spectrum that maximizes or minimizes these parameters related to circadian rhythms.

- More specifically, what has been shown is the ability to **selectively stimulate the visual and non-visual pathway** by changing the light spectrum in real time. The non-visual pathway responds better to light for short wavelengths, through melanopsin, a photopigment expressed by intrinsically photosensitive retinal ganglion cells (iP-RGC). The levels of perceived light intensity and its chromaticity ("color") are determined by photoreceptors called cones. The INN has developed methods to generate variable light spectra with LEDMOTIVE luminaires, which allow us to compensate for the quantities and effects of non-visual ("melanopic") and visual ("photopic") illumination.

- The INN has shown that:
  - ✓ "Blue" light of a narrow bandwidth, at low photopic illumination intensity, suppresses the levels of melatonin with the same effectiveness as a "white" light of a wide bandwidth with the same melanopic illumination intensity but with a higher photopic illumination.
  - ✓ "Cold" white light of a wide bandwidth suppresses the levels of melatonin more effectively than a "warm" white light with the same photopic intensity.
  - ✓ White light suppresses subjective drowsiness as effectively as "blue" light that contains the same melanopic intensity and much more effective than "warm" light. Despite "blue" and "warm" light suppresses melatonin

[16] Research carried out by Group from the director of the INN in Newcastle (UK), Prof. Dr. Anya Hurlbert, http://www.ncl.ac.uk/ion/staff/profile/anyahurlbert.html#background

"The impact of illumination (and above all, of spectrally tunable light) on health will soon have an important role in the design process of a light source that, until now, has been based solely in terms of energy efficiency. It will not only benefit humans, but the return of investment will be compensated in terms of welfare and productivity by a wide margin."

and reduces drowsiness, the effects associated with fatigue don't diminish nor they don't seem to improve performance when completing the tasks proposed to the study subjects. In contrast, "warm" light increases performance in visual attention tasks. "Warm" light, of low melanopic intensity but high photopic is also considered more pleasant than the "blue" light. In this way, it is recommended that, at nightfall, mood and visual performance are being prioritized, while melatonin levels increase naturally using a "warm" light with high photopic intensity, but with a low melanopic intensity.

✓ Finally, the INN has shown that the LEDMOTIVE luminaires can be used in "feedback" mode, together with a series of biosensors and actigraphy monitoring human rest/activity cycles. It has also been demonstrated that changes in the spectral content of light can be activated automatically when warning alert levels drops and these changes in photopic or melanopic intensities serve to regulate alertness.

To conclude, the use of **LEDMOTIVE** technology in a highly demanding environment **allows for the modulation of the circadian cycle**, as well as other parameters associated with productivity and alertness of **patients and people**.

3. System dimensioning

3.1 Light design

To optimize the proposed solution, it is necessary to know different items in the installation such as room(s) dimensions and its limitations due to other types of existing installed equipment like air ducts or machinery to mention few. The furniture distribution, how it's being used and the existence (or lack of) daylight in the room are other type of parameters that should be considered.

By means of this information and following the recommendations set by the international norms, LEDMOTIVE design team can analyze and propose the **best solution in terms of functional use, costs and environmental impact**.

Figure 4. Example of a Smart ICU design

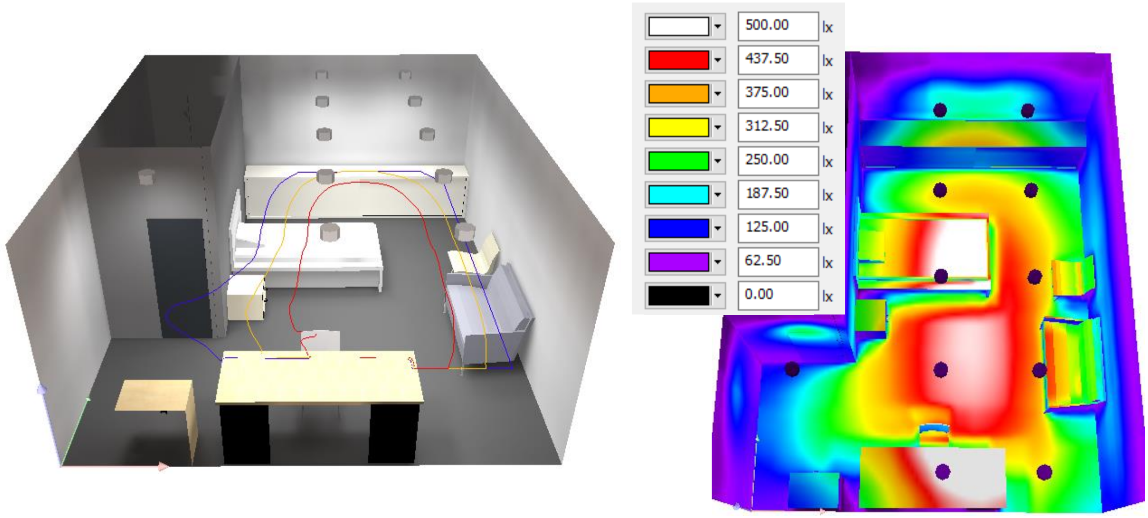

Figure 5. Example of a residential design

3.2 Functional design

In the same way, by analyzing the requirements and the functional usage of a room and the people in it, LEDMOTIVE can advise and adapt the solution to modify the luminous flux, the spectral content of light or both to offer the most appropriate illumination at every time of the day, giving control and full flexibility to the users on a regular basis.

As an example, for the lighting design in the areas shown in previous figures, it was proposed to program a lighting sequence, for the circadian cycle, oscillating between a spectrum corresponding to a CCT of **1850K** (sunset) and a CCT of **6500K** (midday) to emulate the oscillations hours of a sunlight. Luminous flux was also variable, being more intense coinciding with the highest CCT or the central hours of the day as it happens with natural daylight.

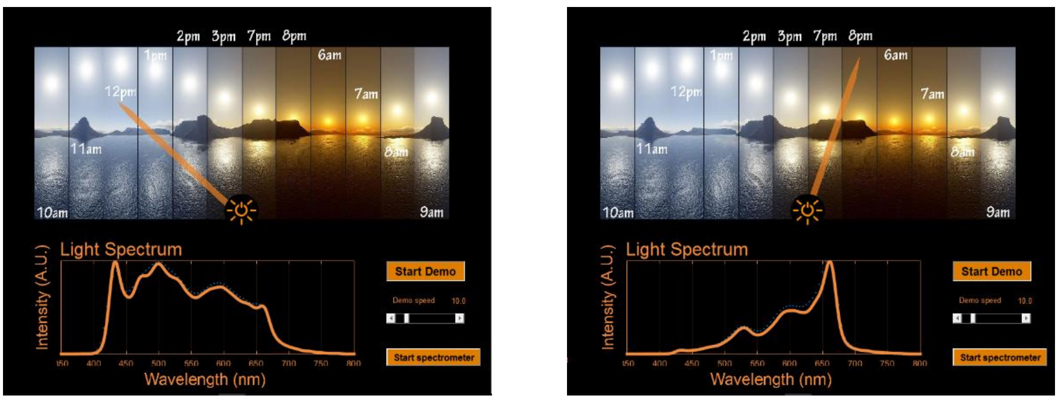

Figure 6. Light spectrum adapted to the circadian cycle

The lighting system proposed by LEDMOTIVE, in addition to accompanying the patient's circadian rhythm, can be integrated into the general control system or a building management system (BMS). In this sense, LEDMOTIVE provides an API over HTTP protocol and offers the necessary support for such software integration.

Through this integration, the lighting system can respond to signals / requests that may come from the BMS, such as:

- **Blue Code** (in critical cases such as cardiac arrest, ventricular fibrillation, etc.): The illumination of a room is raised to the maximum (or optimum) level to achieve an adequate working condition (normally at 4000K) due to an alarm that requires a critical attention. If the same lighting system is used in the corridor, the corresponding luminaire, located at the door, would light in blue color to guide the specialists to the ER room who must attend the corresponding alarm, thus also becoming a **signaling system**.
- **Switch controller**: The lighting system can respond to advanced commands integrated in a switch inside the ER room, allowing manual control of a lighting system. Interrupting the daily lighting cycle, putting a specific light pre-set condition, adjustable dimming or color enhancing are a few examples.
- **Time adjustment signal**: Allows to set the starting of a lighting cycle so that it starts playing at a different time. That is, different ER rooms may be programmed to maintain a time gap in a circadian lighting sequence.

3.3 Light Pattern – Circadian cycle

Considering the aforementioned aspects and with the aim of offering a quality of light always higher than that required in the norms (CRI> 80 in general or CRI> 90 in ICUs), LEDMOTIVE assesses the best spectra to reproduce the cycle of sunlight, always maintaining a high color rendering value (Ra) to favor the observation of the patient independently of the color temperature applied at each moment, and with a much smaller circadian stimulus (CS) for low CCTs (dusk).

To maximize the beneficial effect of the non-visual pathway from the dynamic lighting, following the cycle of sunlight, the system provides a spectral variation, throughout the day, that responds to the following criteria:

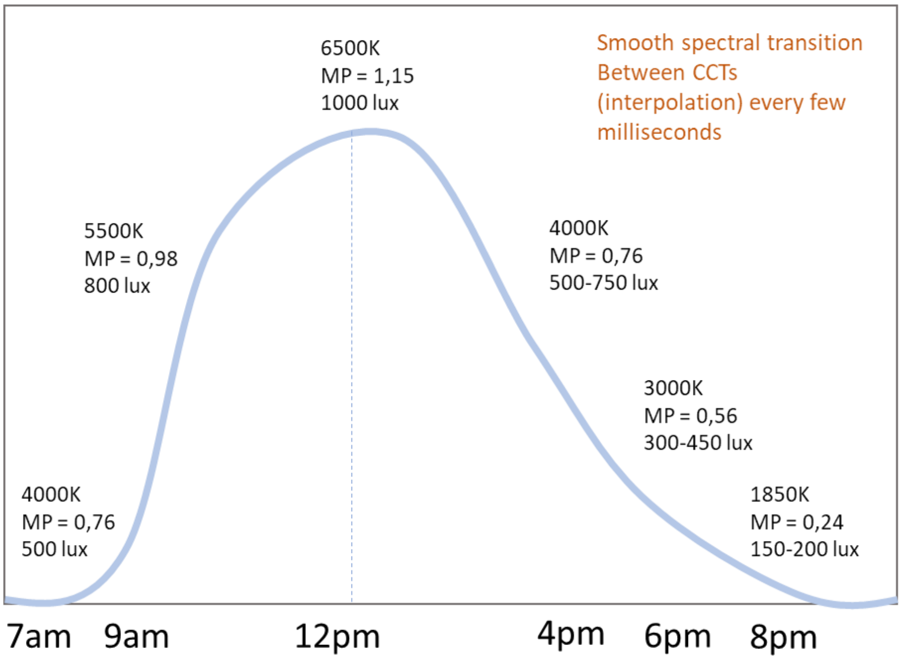

Figure 7. Circadian cycle pattern

LEDMOTIVE intelligent and dynamic solution simulates sunrise and sunset, a 12-hour **automated photo-period of sufficient brightness and 12 hours of reduced light** (relatively dim, with "blue" light inhibited) or darkness:

- Early morning light
  - ✓ In the early hours of the morning, simulation of dawn: beneficial effects on the sleep inertia, daytime well-being and cognitive performance.
- Increase in the intensity of light and more enriched in blue-content
  - ✓ For approximately the first 2 hours after waking up: it prevents the body clock from being delayed (sleeping and waking up later every day)
  - ✓ In response to alerts (at any time of the day / night)
- Diminishing light intensity and blue content: helps relaxation
  - ✓ For approximately the last 2 hours before bedtime: support sleep (faster onset of sleep, deeper sleep, and better quality)
- The light in the night must be handled with care, so as not to interfere in the health

The LEDMOTIVE system allows to individually configure each luminaire (or a group of them, such as those in a ER room) so that it behaves in the way you want always, adapting to the **specific needs** of each occasion.

3.4 Architecture

The LEDMOTIVE lighting system consist of a LED module(s) with spectral tunability and a **communications LIGHT HUB device** design and manufactured by us. Additionally, **manual controls and signaling lights** can be connected to a LIGHT HUB, using standard market protocols or **using the lighting system itself as a signalization** in certain scenarios (alarms, guidance, etc.)

The system allows to access each LED module embedded in a luminaire from any device, fixed or mobile, connected to the Internet through a *Web App*.

An example of a distribution and schematics of the connections are shown in the following figure:

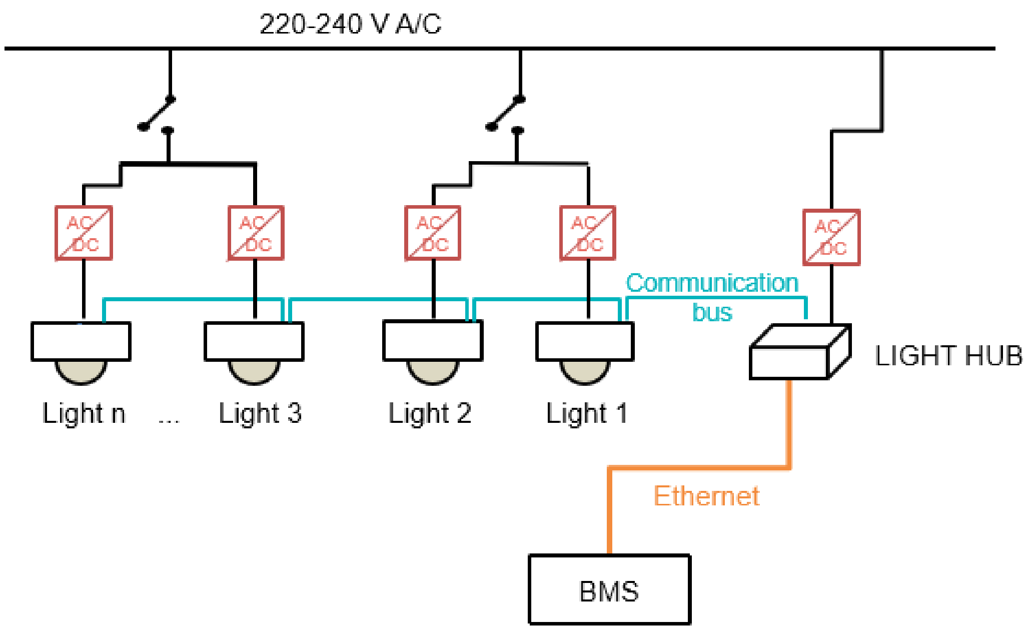

Figure 8. Schematics of the connections

3.5 Main LEDMOTIVE lighting features

The LEDMOTIVE system combines 7 different LED color channels to produce any light spectrum in the visible range. Here are some of its main features:

- **No infrared radiation:** < 5mW/nm in the NIR (780-1400nm). A higher radiation could contribute to the proliferation of bacteria.
- **No ultraviolet radiation:** < 3mW/nm in the UVA (315-380nm). A higher radiation could contribute to the degradation of materials or substances.
- **Independent control of power and color temperature:** thus, it is possible to adjust de level of illumination so that at any color light is always perceived as white(pleasing), to avoid surpassing *Kruithof curve* (where light appears too bluish or reddish).

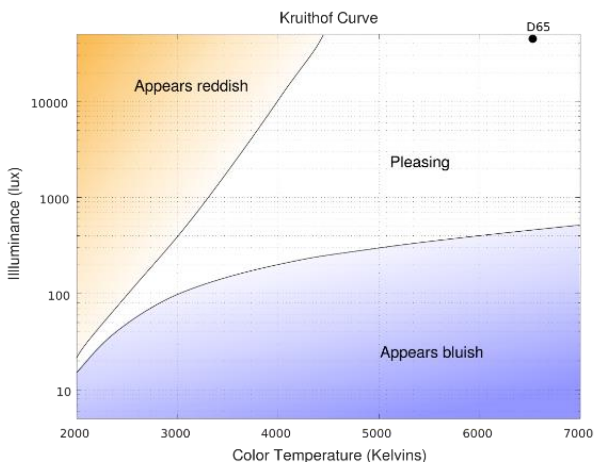

Figure 9. Kruithof curve

- **No flickering:** different LED color channels regulation is carried out at a high frequency to avoid the effect of flickering, which otherwise, could cause discomfort such as fatigue, migraine, photosensitivity and even epileptic attacks.
- **High color accuracy:** The combination of all seven channels avoids of having gaps in the visible spectrum not being covered, assuring a complete color consistency and an illumination with the highest possible quality, reaching a color rendering index close to its 100-max value for any color temperature.
- **Automatic degradation correction** of the spectrum: A closed-feedback loop corrects automatically any spectral degradation due to a temperature fluctuation or ageing of the LEDs.

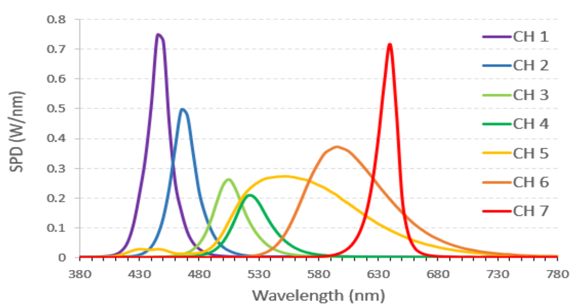

Figura10. LED channels characterization

4. Contact

If you would like to know more details and incorporate the most advanced ***Human Centric Lighting*** system, please contact us and we will advise.

LEDMOTIVE VEGA 07 module responsible for providing an SPECTRALLY TUNABLE LIGHT

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