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Lighting in educational environments: An example of a complete analysis of the effects of daylight and electric light on occupants

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ABSTRACT

Light induces not only visual responses but also non-visual effects, indeed it affects performance, mood, attention and influences the synchronization of the biological clock. Duration, timing, intensity and the spectral power distribution of the light that reaches the eyes can have influence on human circadian rhythm and consequently on health. Given the important impact of the non-visual responses on people wellbeing, developing a model that allows lighting designers to predict them is a fundamental goal.

In this paper a case study is reported: a series of measurements were carried out in a University classroom in order to study daylight and electric light characteristics and also their impact on the human circadian system by calculating melatonin suppression. The results obtained show that not only the intensity but also the SPD of the light received by the eyes plays a significant role on circadian response and the spectral characteristics of internal and external surfaces influence the SPD and therefore the CCT of the light that hits the eyes. Although the working behavior of the human circadian system is not completely understood, the results obtained give the designers new points of view to better evaluate lighting quality and its implications in indoor environments.

1. Introduction

It is now well established that light induces not only visual responses but also non-visual effects; light affects performance, mood, attention and influences the synchronization of the biological clock located in the suprachiasmatic nuclei (SCN), this clock regulates self-sustained rhythms that repeat about every 24 h (e.g. sleep–wake cycle, hormones secretion and others) [1]. This 24 h pattern is maintained thanks to light exposure, but the timing of it along with the light intensity and its spectral power distribution can also cause an alteration of this pattern [2,3].

When the 24 h scheme is altered there is a risk of circadian disruption that has been linked to various health diseases that range from fatigue to increased risk of cancer [4]. Moreover light has a relevant role in improving behaviour, sleep and circadian rhythmicity of older people affected by diseases such as dementia and Alzheimer [5,6].

Therefore it is important to better understand these non-visual responses, however the mechanisms of these responses are not yet fully understood, also considering that the circadian and visual system are different since the human circadian system requires higher levels of illuminance to be stimulated and has a peak spectral sensitivity at shorter wavelengths [7–9].

It also responds differently to the same light stimulus depending upon the time of day: a light stimulus in the morning may advance the timing of the circadian clock (shorten our biological day) and help the maintenance of the 24 h cycle while the same light stimulus in the evening may delay the clock (extending our biological day) [10,11]. The response also seems to be depending on individual differences in the response to a lighting stimulus and the age of a person [12–15]. Moreover rods and cones give impulse to the circadian and visual systems but they do not seem to be strictly necessary for the circadian system regulation. Indeed studies demonstrated that the genetic ablation of these photoreceptors has small effects on the photic circadian phase-shifting response, instead the intrinsically photosensitive retinal ganglion cells (ipRGCs) are central to the circadian system phototransduction [16,17]. The spectrally-opponent (colour) mechanisms in the distal retina that provide synaptic connections to the ipRGCs is also important to the circadian system [18].

In the scientific literature two approaches can be found: one focused on the definition of a circadian photometry based on a sensitivity function, $C(\lambda)$, to be used in the lighting design practice like $V(\lambda)$, while the other approach is focused on understanding

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human response to light which does not seem to follow additivity laws [19–23]. An example of the first approach is represented by the studies conducted by Gall et al. [19], Pechacek et al. [20], Gochenour et al. [21], Wandachowics [22], based on action spectra for melatonin suppression response in humans derived by Brainhard et al. [24] and Thapan et al. [25], characterized by a peak sensitivity in the visible short wavelengths range. These studies consist in the prediction of a light source's circadian impact conducted through softwares like RADIANCE or Daysim. The second approach is represented by the model presented by Rea et al. in Ref. [23] which allows to predict the effect of a given polychromatic or monochromatic lighting stimulus on the circadian system in terms of nocturnal melatonin suppression. The first approach is particularly important for applications in the lighting design practice since this circadian sensitivity function can be introduced in softwares and instruments to evaluate the potential circadian impact of a lighting source. However this $C(\lambda)$ function represents a simplification of the circadian system sensitivity and, as previously stated, the response of this system depends on different photoreceptors and interactions between them and has different effects on humans. Moreover measurements in real environments can also bring a deeper knowledge of these phenomena. Therefore, even though it is certainly more difficult to apply, the approach based on the prediction of melatonin suppression values consequent to the exposure to a given light source seems to be more accurate. None of this approach can fully represent the response of the circadian system, which is still under investigation, but they represent the first steps in developing a method that allows lighting designers to predict non-visual effects of light [26,27] and they will be upgraded as new information about the circadian system will be available.

Given these premises, the case study reported in this paper consists in a series of measurements carried out in a University classroom with different sky conditions in order to study daylight and electric light characteristics in this environment and also their impact on the human circadian system.

The procedure illustrated in Ref. [28] was used to evaluate the circadian impact of lighting sources by calculating nocturnal melatonin suppression from irradiance spectral distributions of the light reaching the eyes. It represents an improvement of the model reported in Ref. [23] obtained through studies conducted to test the utility of the model. Since the mechanism of non - visual responses is not fully understood this method is likely to be revised in the future but until now it is one of the most accurate because it tries to take into account the contributions of all the photoreceptors known to stimulate the circadian system: rods, cones, intrinsically photosensitive retinal ganglion cells (ipRGCs), the spectral opponent blue–yellow channel and also their interactions.

According to previous literature [2,8,9], the impact on the circadian system of a lighting source seems to depend on various factors and in particular on the light quantity and spectral power distribution (SPD). Therefore the calculated melatonin suppression values were compared with illuminance values and correlated colour temperatures (CCTs) to investigate if and how they are linked. Moreover the spectral distribution of the light reaching the eyes was also analyzed and compared with the spectral power distributions of the electric and sky light to evaluate the influence of the environment on the light that hits the eyes.

Similar measurements in the same classroom during different seasons and in other environments are planned with the ultimate aim of developing design guidelines.

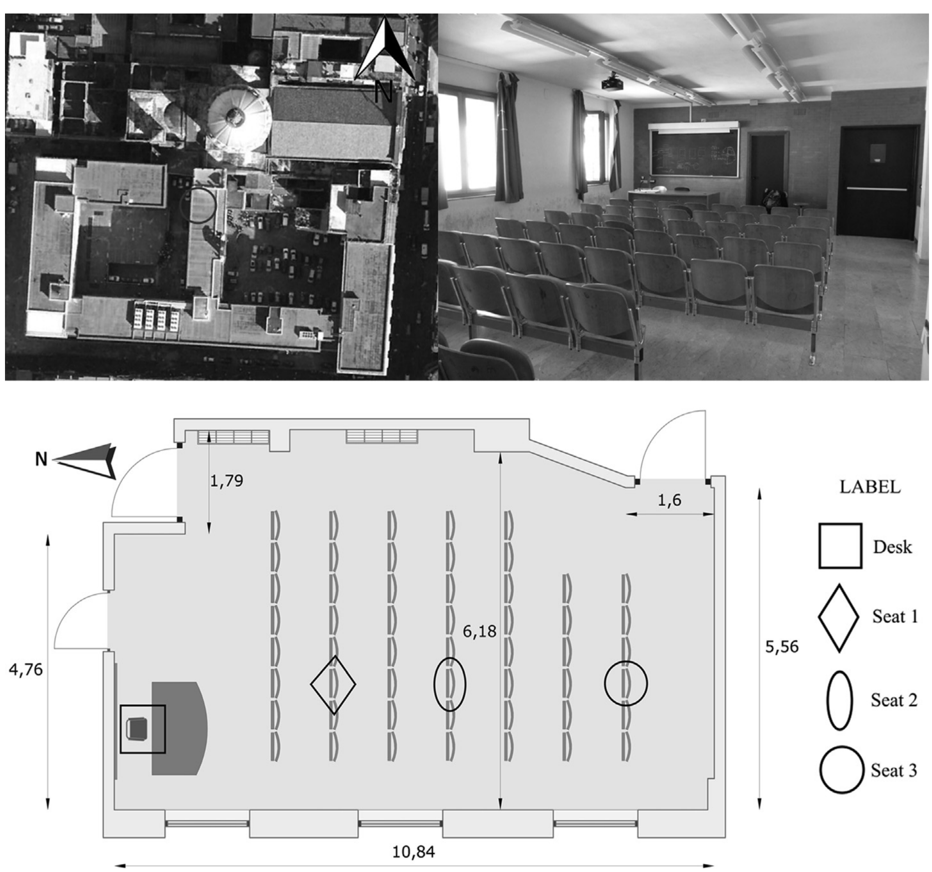

Fig. 1. Urban localization, photo of the classroom and measured plan of the classroom and label.