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Daylighting offices: A first step toward an analysis of photobiological effects for design practice purposes

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ABSTRACT

The research presented in this paper reports an analysis of daylight in three offices with different exposures and characteristics located in Naples (Italy).

The goal was to fully investigate daylight characteristics, also considering the circadian impact of daylight entering these offices, with the hope to develop guidelines to better assess daylight quality in built environments.

One of the main findings of this research is that the spectral distributions and CCTs of the light reaching the eye of a person seated at the desk in these offices are similar irrespective of the offices' different characteristics (dimensions, surfaces' spectral reflectances, external obstructions, etc.) and different sky's conditions. Moreover it was found that eye level irradiances and their circadian impact is similar to those of D50 and D55 CIE standard illuminants. The same measurements will be carried out in other seasons and a comparison between measured values and software simulated ones is also planned.

1. Introduction

The study of daylight availability in indoor environments is extremely important for lighting designers and building planners since it has the potential of improving the users' wellbeing and performance and it also allows to reduce energy consumption [1,2]. Therefore it is necessary to study strategies to maximize its entrance while avoiding discomfort effects and also to correctly integrate it with electric light with the goal of achieving a remarkable energy saving [3,4].

Daylight is also the best light source available in terms of color rendering properties, since its spectral power distribution (SPD) contains all the wavelengths in the visible spectrum and because our eyes have adapted to daylight in the course of millennia.

Moreover light is known to be the main zeitgeber of the circadian system, which is the biological clock located in our brain [5]. This clock controls circadian rhythms, a series of biological processes of our body that repeat themselves with a cycle length of about 24 h.

The cycle length of the circadian system is not exactly 24 h so the circadian clock needs a daily synchronization to maintain a 24 h period; this entrainment is performed with a regular exposure to light and darkness [6].

Circadian rhythms are found both in animals and humans, with different characteristics, as a result of the adaptation to life on this planet. This mechanism has evolved during the millennia and is mostly adapted to daylight since, until last century, it was the main light source available and people's activities were carried out mostly with daylight [7].

The introduction of electric light determined the exposure to light in hours of the day when usually our body is not supposed to receive light and this may lead to an alteration of the circadian clock's period. In fact studies have shown that working under high intensity lamp at night significantly disturb the circadian rhythm [8].

When the circadian system's period is not 24 h there is a disruption that has been linked to various health diseases including cancer [9–11]. Given this strong relationship with people's health the prediction of the circadian impact of a light source is a topic of great interest nowadays.

The variation of the hormone melatonin's level in humans' body during the day is one of the most known circadian rhythms; this hormone is part of the system that regulates the sleep/wake cycle and when its concentration in the blood reaches certain levels it causes drowsiness [12]. Therefore melatonin suppression is used as an index of the capability of a light source to influence the circadian

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system. It was demonstrated that blue light (460 nm) has the strongest effect on melatonin suppression in humans and has also significant effects on alertness and cognitive performance [13–15]. Moreover melatonin suppression in humans seems also to depend on the intensity of light [16].

So far the working of the circadian system's response to a light stimulus is not completely understood and different models to predict this response have been proposed but it is too early to establish a reference model. Brainard et al. [17] and Thapan et al. [18] proposed two action spectra for melatonin suppression in humans, based on experimental data, that show a peak sensitivity at about 460 nm; these two studies provided the basis for the development of other models of circadian phototransduction such as those proposed by Gall et al. [19], Pechacek et al. [20].

Also based on those two sets of data is the model by Rea et al. [21] that allows to calculate the circadian impact of a light stimulus, expressed in terms of nocturnal melatonin suppression, determined by an hour long exposure to light. This model has been modified in the course of the years [22,23] and it is one of the most accurate, since it takes into account the contributions of different photoreceptors and the spectral opponency, at the same time it is relatively easy to apply compared to other models.

The current knowledge of the circadian system does not allow to prescribe a minimum or recommended circadian stimulus value. From these premises it is clear that analyzing and being able to simulate the availability and characteristics of daylight in built environments and predict its circadian impact is extremely important to guarantee both users' wellness and energy savings.

Daylight is the subject of many researches published through the years; a conspicuous number of them have focused on the definition of new methods to replace the daylight factor (DF) in the quantification of the amount of daylight available in an indoor environment [24–27].

Other studies have addressed the problem of simulating daylight, given its variability that needs to be taken into account, and proposed different approaches [28–31]. Few studies have dealt with non visual effects of daylight and included them in a daylight's quality analysis [32–34]; this topic is addressed in this paper by illustrating the results of a research conducted in three offices with different exposures located in Naples (Italy).

The goal is to carry out a global analysis of daylight including both visual and non visual issues and to investigate if there is any similarity between the three offices by comparing the results obtained. Moreover another aim is to continue to investigate the effect of internal and external surfaces on the spectral distribution of the light reaching the eye as it was previously done in two studies by the same authors [35,36].

Daylight measurements were carried out for about a month around summer solstice and the circadian impact of the light arriving at the eyes of a person seated at the desk was calculated using a procedure developed by Rea et al. and described in the method section [22,23]. The same measurements will be carried out in other seasons in order to fully understand the variations of daylight during the year in these three environments. Hopefully after these measurements it will be possible to obtain helpful indications for lighting designers.

2. Method

Measurements were carried out in different days, starting from 31 May 2013 and ending on 3 July 2013, in three offices of the Department of Industrial Engineering located at the seventh floor of one of the University of Naples Federico II's buildings.

The offices are indicated as Office 1 (OF1), Office 2 (OF2) and Office 3 (OF3) and Fig. 1 shows their urban location and external obstructions. OF1 has a westerly exposure and is indicated in Fig. 1 with a triangle, OF2 has an easterly exposure and is indicated with a circle, while OF3 has a southern exposure and is indicated with a rectangle. Fig. 2 reports the measured plans of the offices. Each office is 3 m high.

Fig. 3 reports a measured drawing of the offices' windows and the glasses' spectral transmission, OF1 has three double pane glasses while OF2 and OF3 have two double pane glasses. The offices' glasses have all the same characteristics which are the following: external and internal glasses are 4 mm thick, insulation gap is made of air (12 mm thick), g-value = 0.75, transmittance = 67.6%, light transmittance (D65) = 81.5%. The window to walls ratios are 37% for OF1, 27% for OF2 and 24% for OF3.

Fig. 4 shows the spectral reflectances for all the offices' surfaces, detected with a Konica Minolta CM – 2600d spectrophotometer.

The solar diagram for the measurements' period is reported in Fig. 5.

Table 1 lists monthly turbidity values for Naples as found on Satel – light website [37].

Fig. 1. Urban location and external obstructions of the three offices.