Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 78 (2015) 3138 – 3143

Energy Procedia

6th International Building Physics Conference, IBPC 2015

Methods to evaluate lighting quality in educational environments

Laura Bellia[a,*], Gennaro Spada[a], Alessia Pedace[a,b], Francesca Fragliasso[a]

[a]Department of Industrial Engineering, University of Naples Federico II, Piazzale Tecchio 80, Naples 80125, Italy
[b]Department of Energy, Information Engineering and Mathematical Models, University of Palermo, Viale delle Scienze Ed.9, Palermo 90128, Italy

Abstract

The current standard for lighting of indoor work places (EN 12464-1) essentially prescribes values of photometric quantities (illuminance, Unified Glare Index, etc.); therefore it does not allow a comprehensive analysis of the luminous environment. In Italy, educational buildings do not always comply with the standard requirements for lighting. Therefore an analysis of their current state is needed and this paper illustrates two methods, developed by the authors, to carry out this investigation: the former is based on the analysis of luminance maps obtained through the HDR imaging technique whereas the latter focuses on the evaluation of non-visual effects of light.
© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
Keywords: lighting quality; HDR imaging; educational environments; non-visual responses; daylight.

1. Introduction

Light has a great influence on humans, indeed it allows vision but it is also related to a series of effects, known as non-visual responses, which include for example melatonin suppression, heart rate and alertness level variations [1,2]. These effects depend on several characteristics of the light that reaches an user's eyes, including the duration of the exposure to a light stimulus [3], therefore they are particularly relevant in environments where people spend most of their day such as educational environments. Therefore the analysis of lighting quality in indoor environments should also include the evaluation of these effects in addition to the verification of the respect of the standard for the lighting of indoor work spaces (EN 12464-1 [4]), which is based on the prescription of illuminance levels and uniformity, Unified Glare Index (UGR) limit values and Color Rendering Index (CRI) values.

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: author@institute.xxx

1876-6102 © 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.770

Guaranteeing a good lighting quality in an educational environment is a complex task, first of all people who spend most of their day in it carry out different activities and belong to different age classes (children, teachers, staff, etc.). Moreover in an educational environment very different visual tasks are performed, such as communication between children and between them and the teacher; reading and/or writing on desks and on the blackboard; etc. Frequently these visual tasks are carried out at the same time and, therefore, to accurately analyze lighting quality in existing educational environments, there is the need of instruments that allow to carry out fast measurements on several visual tasks at the same time. This is also extremely important when in presence of daylight, which characteristics may vary rapidly. Such measurements are impossible to carry out with traditional instruments, such as luxmeters, therefore Bellia et al. [5,6] proposed an alternative measurement technique based on the high dynamic range (HDR) imaging technology.

As reported before, the evaluation of non-visual responses is linked to the analysis of light's characteristics at the users' eye level and therefore such measurements are also needed. At the present time, given the current knowledge of non-visual responses, it is not possible to calculate the effect of a light stimulus in a given non-visual response. However several models to predict the impact of a light stimulus on the circadian system were proposed in recent years and they can be used until further advancements are made in this research field.

It is extremely important to highlight that, in Italy, many educational buildings do not even comply with the standard requirements for lighting and therefore they frequently show severe problems in terms of comfort, visual performances and wellbeing. In order to identify and solve these problems an analysis of the current state of educational buildings is necessary and this paper illustrates two methods, developed by the authors, to perform these analyses. The first one is based on the HDR imaging technique, the second one is founded on the measurement of light's characteristics at users' eye level to evaluate non-visual responses.

2. Methods and results

As reported before a great problem in field measurements carried out in educational environments is the presence of several visual tasks related to the different educational activities. Moreover it is also important to ensure an adequate entrance of daylight to save energy, improve the performances of teachers and students and to help the entrainment of their circadian system [7]. Field measurements in presence of daylight can be tricky since this light source's characteristics may vary rapidly, therefore there is the need to perform fast measurements on several visual tasks at the same time. This is impossible to achieve with standard instruments and for this reason the video-luminancemeter comes in handy, it is a high resolution instrument with a wide field of view and high dynamic range. Thanks to the video luminance meter, which uses the HDR technique, it is possible to perform different types of field measurements with a single instrument and one set of measures [8,9].

The HDR technique is based on the acquisition of different images of the same scene using different settings. This technique is used by the system developed at the Photometry and Lighting Laboratory of the Department of Industrial Engineering of the University of Naples "Federico II", it includes a digital reflex camera Canon EOS 20D, equipped with a photopic filter and a Matlab-based software for data management and processing.

This system uses three setups that differ only for the image shutter time which are respectively equal to 2s, 1/15s and 1/500s. For each one of them there is an operating range that goes from the minimum sensitivity threshold of the sensor to its saturation. Shutter times used to measure low, medium or high luminance levels are respectively equal to 2s, 1/15s and 1/500s. By combining together the three ranges it is possible to visualize a luminance map that provides, at the same time, low, medium and high luminance values of the whole scene. Therefore the instrument works through the separate analysis of the different pixels that form the scene, classifying them basing on the luminance range to which they belong and simultaneously providing the geometric data related to the corresponding solid angle and corrected solid angle. The ranges could also be more than three and set up in a different way, by conveniently modifying set up points. Therefore luminance mapping allows to dispose of the luminance values of a whole scene with a considerably high spatial resolution, which is particularly useful for the measurement of sources' luminance. Moreover it provides a series of information that can be processed for different purposes such as glare and luminance contrast analysis. By setting suitable targets in the scene with a known reflection factor and lambertian reflectance in correspondence of visual tasks' surfaces, it is also possible to obtain illuminance values on targets from the luminance map. This method allows to achieve a simultaneous illuminance evaluation in all the points of a conveniently defined grid, however it is important to keep in mind that this method can only be applied to lambertian surfaces.

In the case of educational environments the possibility to obtain, in a fast and simultaneous way, illuminances on measurement grids makes it easier to verify different light scenes with electric light and to define in a fast and precise way the average daylight factor. To test the reliability of such a system tests were carried out in some classrooms of the "Don Lorenzo Milani" school located in Arzano, Naples. Illuminance values on horizontal surfaces obtained with the HDR technique and with a Konica Minolta T10 luxmeter were compared, measurements were carried out with daylight plus electric light and with only daylight. In Figure 1 an example of luminance maps obtained using the HDR technique is reported.

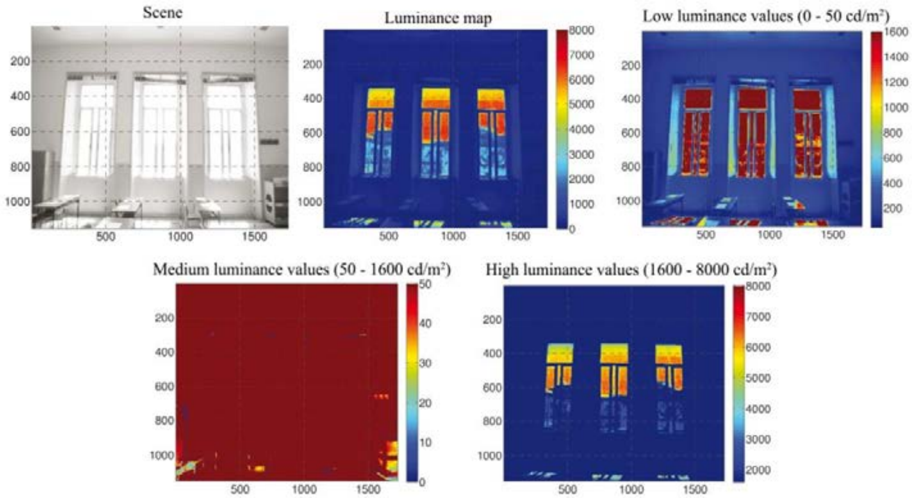

Fig. 1. Luminance maps obtained through the HDR imaging technique

Table 1 illustrates a statistic analysis of the luminance maps reported in Figure 1.

Table 1. Statistic report.

Luminance values	Calibration curve (shutter)	Luminance range (cd/ m^2)	Average luminance (cd/m^2)	Pixels	%	Solid angle (sr)	%	Corrected solid angle (sr)	%
Low	2s	Min - 50	28	59919	3,01	0,0358	2,40	0,0059	0,93
Medium	1/15s	51 -1600	285	1708867	85,84	1,2695	84,94	0,4986	78,38
High	1/500s	1601 - max	4376	221870	11,15	0,1893	12,67	0,1316	20,69
Total				1990656		1,4946		0,6361	

Figure 2 shows an example of targets' location on the teacher's and children's desks to obtain illuminance values from luminance maps.

Fig. 2. Example of target location for illuminance values' detection.

Table 2 reports an example of illuminance values calculated from the luminance maps obtained through the HDR technique.

Table 2. Average illuminances on targets [lx].

Tasks	Target 1	Target 2	Target 3	Target 4
Desk n°1	459	421	385	409
Desk n°2	752	724	584	574
Desk n°3	1200	775	1232	881
Teacher's desk	479			
Blackboard	250			
Entrance	327			

It is also important to evaluate non-visual responses. For this purpose light's characteristics (such as spectral distribution, intensity, etc.) at the users' eye level should be measured.

An example of such measurements carried out in an educational environment can be found in [8], in that case a luxmeter and a spectroradiometer were used. Figure 3 shows the measured plan and a photo of the classroom; in the plan the positions where the measurements were performed are also reported.

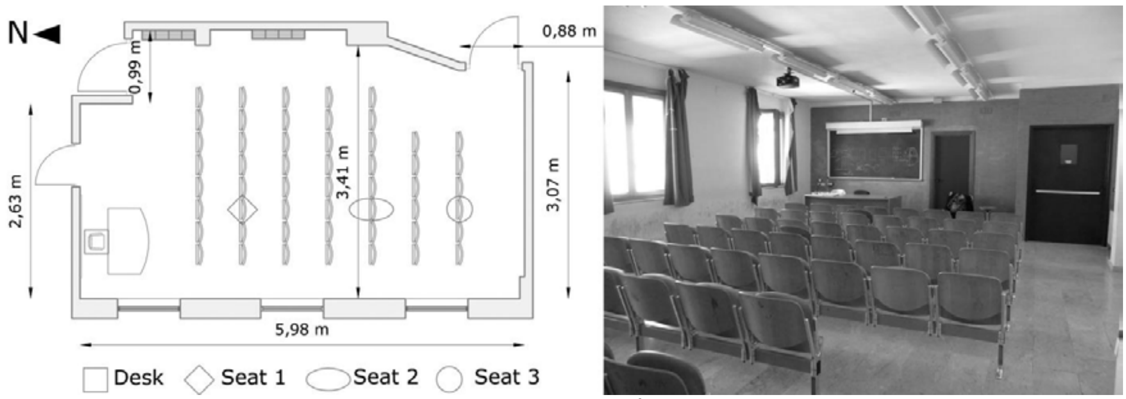

Fig. 3. Measured plan and photo of the classroom.

During two typical winter days, one with a clear sky and the other with an overcast sky, several characteristics of daylight were recorded each hour from morning to twilight, such as sky spectral power distributions (SPDs), eye level and desk illuminances, eye level CCTs and spectral irradiances, outdoor illuminances. The same measurements were also performed for the electric lighting system. Eye level measurements were carried out with three different tilt angles (0°,15° and 45°) of the spectroradiometer in order to take into account the fact that the position of a person's head is not fixed.

It has been reported before that, although there is no universally accepted method to evaluate non-visual responses, several models to predict the impact of a light stimulus on the circadian system were proposed during the years. In [10] a model of circadian phototransduction by Rea et al. [11] was used, which allows to evaluate the circadian impact of a light stimulus in terms of melatonin suppression. The first step is the calculation of spectrally weighted irradiance for the human circadian system (circadian light - CL_A) expressed in weighted W/m^2, then the circadian stimulus CS, expressed in percentages of melatonin suppression, can be determined. The input of this model are spectral irradiances and, for the analysis of light quality in the classroom, eye level spectral irradiances measured with daylight and electric light were used as input. Figures 4 and 5 report CS values, horizontal plane and eye level illuminances and eye level CCTs respectively for the desk and seat 2 during the overcast and clear sky days, with the electric light and also with the combination of electric light and overcast sky.

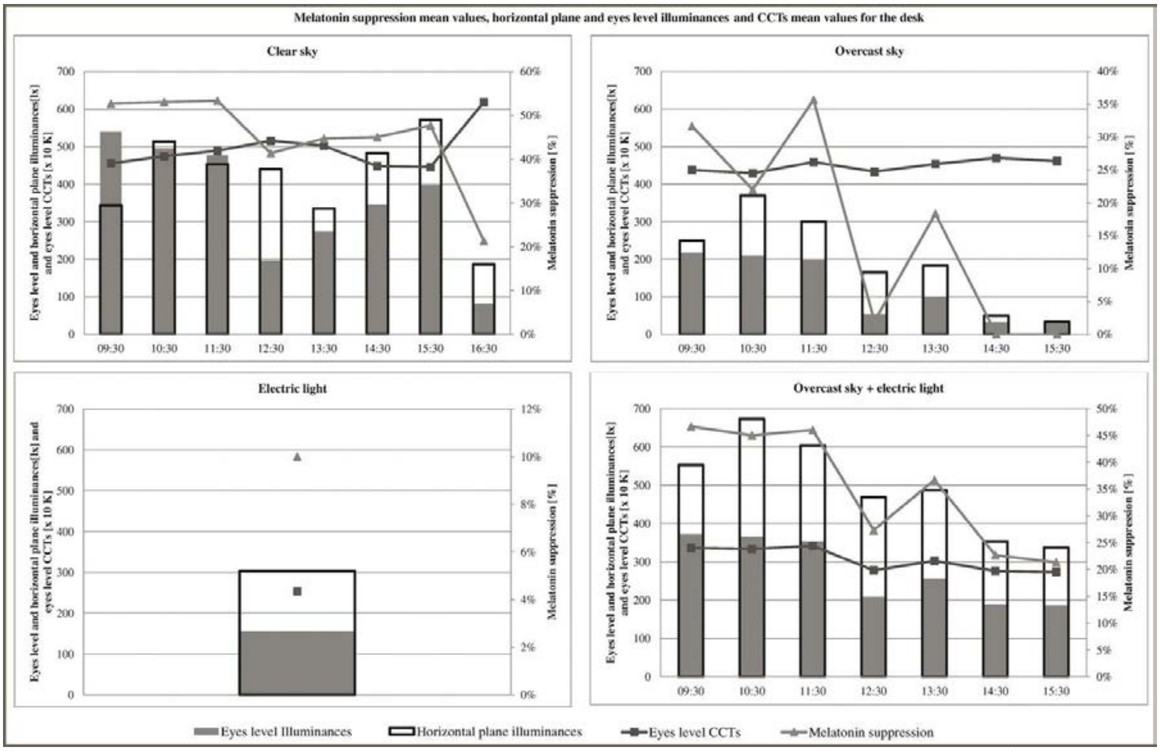

Fig. 4. Eye level and horizontal plane illuminances, eye level CCTs and melatonin suppression values for the desk.

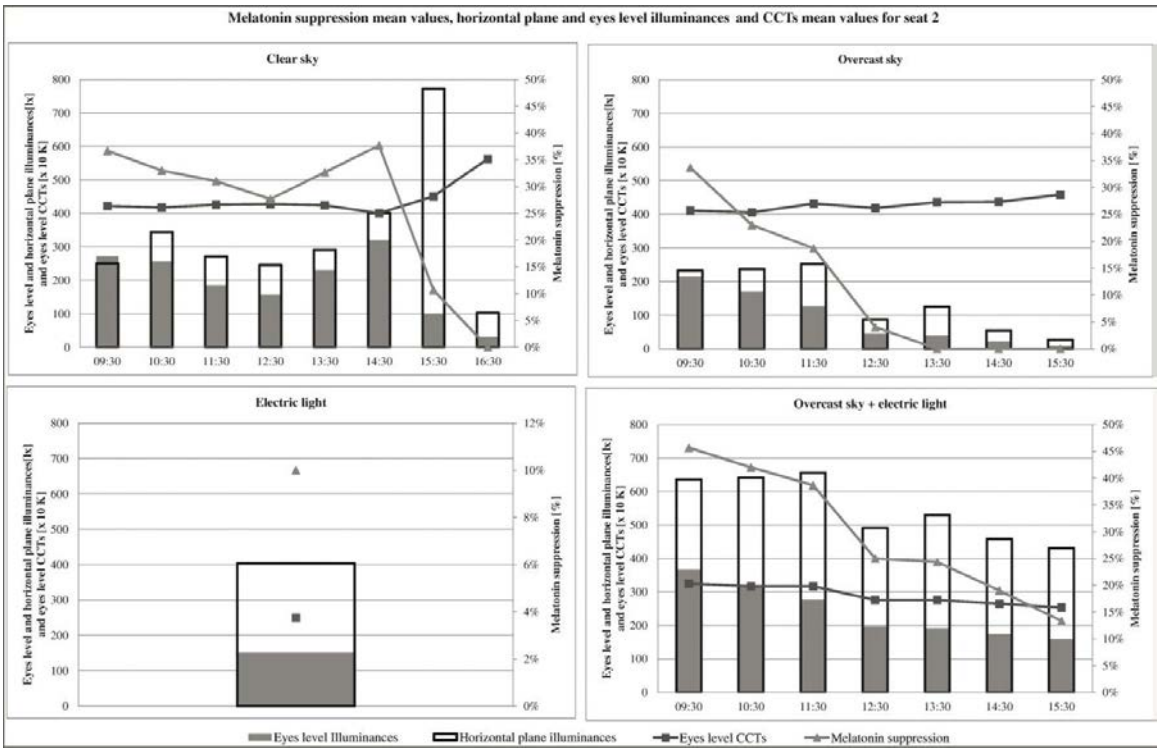

Fig. 5. Eye level and horizontal plane illuminances, eye level CCTs and melatonin suppression values for seat 2.

It can be noted from the graphs reported before that eye level CCTs are always comprised between 4000K and 6000K, moreover the trends of melatonin suppression values are completely different from CCT values' ones meaning that there is no direct relationship between them. On the contrary, it can be observed that there is a link between eye level illuminances and melatonin suppression, in accordance with studies that reported the link between light intensity and the impact on the circadian system [12].

3. Conclusion

The goal of this paper is to illustrate innovative measurements techniques for field measurements in existing educational environments as well as a methodology to carry out these investigations.

In summary, to fully investigate lighting quality in educational environments simultaneous measurements on several visual tasks should be performed and for this purpose the HDR imaging technology is extremely helpful.

The analysis of lighting quality should not only focus on the respect of the EN 12464-1 requirements, but also on the analysis of light's characteristics at the users' eye level in order to apply models to evaluate non-visual effects of light.

References

[1] Lucas R J, Peison S N, Berson D M, Brown T M, Cooper H M, Czeisler C A, Figueiro M G, Gamlin P D, Lockley S W, O'Hagan J B, Price L L A, Provencio I, Skene D J, Brainard G C. Measuring and using light in the melanopsin age, Trends in Neurosciences 2014, 37(1): 1-9.

[2] Cajochen C, Munch M, Kobialka S, Kräuchi K, Steiner R, Oelhafen P, Orgül S, Wirz-Justice A. High sensitivity of human melatonin, alertness, thermoregulation, and heart rate to short wavelength light. The Journal of Clinical Endocrinology & Metabolism 2005, 90(3), 1311-1316.

[3] Gooley J J, Rajaratnam S M W, Brainard G C, Kronauer R E, Czeisler C A, Lockley S W. Spectral Responses of the Human Circadian System depend on the Irradiance and duration of exposure to light. Science translational Medicine 2010, 2: 31 - 33.

[4] EN 12464-1 "Lighting of work spaces - Part I: Indoor work places".

[5] Bellia L, Musto M, Spada G. Illuminance measurements through HDR imaging photometry in scholastic environment. Energy and buildings 2011, 43(10), 2843-2849..

[6] Bellia L, Spada G, Pedace A. Lit environments quality: A software for the analysis of luminance maps obtained with the HDR imaging technique. Energy and Buildings 2013; 67, 143–152.

[7] Boyce P, Hunter C, Howlett O. The benefits of daylight through windows. New York: Lighting Research Center, Rensselaer Polytechnic Institute; 2003.

[8] M. Moeck, S. Anaokar, Illuminance analysis from high dynamic range images, Leukos 2006; 2 (3): 211–228.

[9] J. Mardaljevic, B. Painter, M. Andersen, Transmission illuminance proxy HDR imaging: a new technique to quantify luminous flux , Lighting Research and Technology 2009; 41: 27–49.

[10] Bellia L, Pedace A, Barbato G. Lighting in educational environments: An example of a complete analysis of the effects of daylight and electric light on occupants. Building and Environment 2013; 68: 50-65.

[11] Rea M S, Figueiro M G, Bierman A, Hamner R. Modeling the spectral sensitivity of the human circadian system. Lighting Research and Technology 2011, 0: 1-12.

[12] Duffy J F, Czeisler C A. Effect of light on human circadian physiology. Sleep medicine clinics 2009, 4 (2), 165-177.