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Integration of a luminescent solar concentrator: Effects on daylight, correlated color temperature, illuminance level and color rendering index

Niccolò Aste [a], Lavinia Chiara Tagliabue [a,*], Pietro Palladino [a], Daniele Testa [b]

[a] Architecture, Built environment and Construction Engineering Department – Politecnico di Milano, via Bonardi 9, 20133 Milan, Italy
[b] Eni S.p.A, Research Center for Non-Conventional Energies – Istituto ENI Donegani, Research and Technological Innovation Department, via Giacomo Fauser, 4, 28100 Novara, Italy

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Abstract

The paper deals with the integration of a luminescent solar concentrator (LSC) realized with a yellow dye produced by ENI Donegani Institute and analyzed by Politecnico di Milano. The LSC component has the capability to produce electricity and substitute transparent surfaces into the building envelope using inclinations (e.g. vertical walls) and orientation (e.g. different from south) not optimal for standard photovoltaic system integration. The visual effects of the dyed LSC integration are analyzed to understand potentials and critical points of the use of such a component in the built environment. Systematic tests were conducted to evaluate the visual performance parameters related to the application of the yellow LSC component as fanlight in a partially glazed south façade of an office space, through experimental measures taken on a scaled physical model. The main effects can be ascribed to the increasing of the illuminance level and to the reduction of correlated color temperature whereas the color render index shows changes that in some cases have to be carefully assessed such as when color identification is the specific visual task.

Keywords: Luminescent solar concentrator; Illuminance level; Correlated color temperature; Color rendering index

1. Introduction

Luminescent Solar Concentrators (LSCs) are solar active devices (Goetzberger and Greubel, 1977; Goetzberger, 1978; Swartz et al., 1977) that can be suitable to be integrated in architecture (Van Sark, 2013), preserving transparency of the envelope and therefore assuring profitable energy production and light exploitation into the building spaces. The interest in LSC comes from the opportunity to reduce the photovoltaic surface, which is located only on the edges of the component, and the related costs and to improve daylighting into the indoor spaces. Office buildings are often realized with wide transparent façades, causing in many cases glare and overheating problems to the users (Nazzal, 2005; Fadzil and Sia, 2004; Kim and Kim 2012; Shin et al., 2012). However the architectural language seems to be unavoidable connected to the transparent image of this kind of the buildings in which shading systems, to control and manage the daylight, have to be considered even into the design phase. LSCs can be applied as part of the transparent envelope paying attention to the color due to the dyes dispersed into the plastic bulk used. When transparency and a more extensive use of diffuse

* Corresponding author. Tel./fax: +39 02 2399 9469.
E-mail address: chiara.tagliabue@polimi.it (L.C. Tagliabue).

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Nomenclature

Variables and parameters
λ wavelength (nm)
V luminous efficiency (–)
$V(\lambda)$ photopic function (nm)
K luminous efficacy (lm/W)
E illuminance (lx)
Φ flux (W, lm)
UGR unified glare rating (–)
R_a general color rendering index (–)
*R*1 to *R*15 special color rendering indexes (–)
CCT correlated color temperature (K)
SPD spectral power distribution (W/m^2 nm)
τ transmission coefficient (–)

Subscript
λ spectral
m average value
min minimum value
v visible
e radiant
CG clear glass
LSC luminescent solar concentrator

radiation are required, LSCs components may be a good alternative to traditional photovoltaic systems (Wiegman and Van Der Kolk, 2012). However their durability and technical–economic competitiveness have to be ensured (Debije and Verbunt, 2012).

This paper describes the first daylighting evaluations carried out on a new LSC prototype, developed by ENI Donegani Institute (Scudo et al., 2010) and analyzed by Politecnico di Milano, in which photoluminescent dyes are dispersed into a polymethylmethacrylate (PMMA) sheet. The dyes developed in the first research phase and dispersed in the plastic transparent slab provide a yellow color to the component. Photovoltaic performances have been dealt with in other studies.

The dyes dispersed in the transparent slab are: DTB (4,7-di(2-thienyl)benzo[c]1,2,5-thiadiazole) synthesized by ENI, and DPA (9,10-diphenylanthracene), a commercial dye (Patent Number(s): WO2011048458-A1; WO2011048458-A8) (Aste et al., 2015). The curves of absorption and photoluminescent intensity of emission related to the two dyes are shown in Fig. 1.

Experimental measurements on the absorption and emission spectra of DPA and DTB dyes, carried out at ENI Donegani Institute, are represented in Fig. 1. The two parameters are defined below.

Absorbance is the logarithmic ratio of the amount of radiation falling upon a material to the amount of radiation transmitted through the material. Absorbance at a certain wavelength of light (λ), denoted A_λ, is a quantitative measure expressed as:

$$A_\lambda = \log_{10}\frac{I_0}{I}$$

i.e., as an unsigned logarithmic ratio between I_0, the radiation falling upon a material (the intensity of the radiation before it passes through the material or incident radiation) and I, the radiation transmitted through a material (the intensity of the radiation that has passed through the material or transmitted radiation).

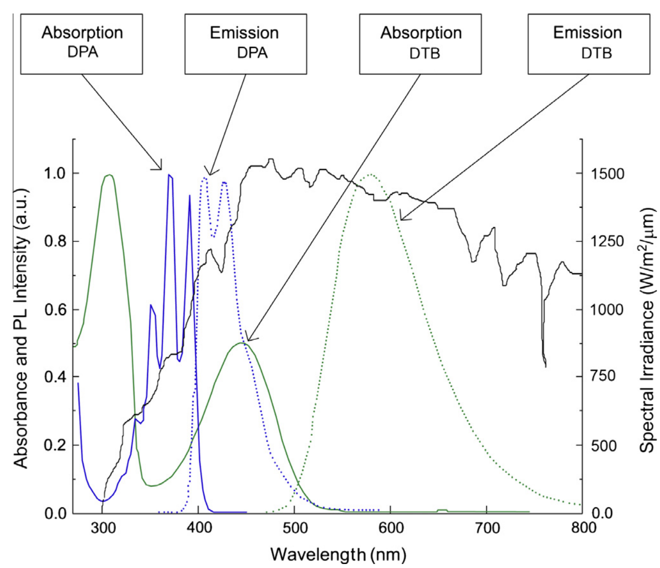

Fig. 1. Absorbance and emission spectra of DTB and DPA and Solar spectrum (Air Mass 1.5);.

Photoluminescence Intensity is the ratio between emitted and absorbed photons, expressed also as fluorescence quantum yield ($\Phi_{PL} = 0.83$ for DPA and $\Phi_{PL} = 0.90$ for DTB).

The yellow LSC component can be integrated in different parts of the building envelope carefully considering the color affection on visual comfort parameters (Lynn et al., 2012; Palladino, 2005; Palladino 2002; Coppedè and Palladino 2012).

The integration of the yellow LSC changes the quality of light in the indoor space, the light becomes warmer as the correlated color temperature (CCT) is lowered in comparison with a clear glass solution. The decrease of the CCT produces favorable effects on visual comfort and can enhance the cold light in climates in which covered sky are prevailing. Moreover the color of the dyes produces a spectral shifting of the wavelength that comes closest to