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Review

Advanced daylighting evaluation applied to cultural heritage buildings and museums: Application to the cloister of Santa Maria El Paular

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ABSTRACT

A method to evaluate the risk of using daylight in museums and cultural heritage exhibitions is presented along this study. Although daylight is an ecological and sustainable source of energy and sometimes also an intrinsic part of the artwork, the use of Natural lighting may cause damages in them due to the difficulty of controlling its variability. The developed method quantifies the damage produced to the artworks by daylight compared to artificial light taking into account the level of radiation and its spectral distribution in space and time by comparison with the damage caused by an Illuminant A (Global Risk Factor). The method, applied to the permanent paintings exhibition in the cloister of the fifteenth century of the Monastery of Santa Maria de El Paular, certifies that the control and exploitation of Natural Light should consider an optimal balance between exposure and damage.

1. Introduction

Lighting is one of the most important factors to appreciate the artistic and historical elements but it should be very well controlled since electromagnetic radiation can damage the exposed art material [1].

The control of light is so far based on certain regulations and guidelines, such as those contained in the CIE 157:2004 [2]. However, there are spaces in which Natural Light, so difficult to control caused by its variability, is the source of illumination, due to the type of construction or to the artistic interest.

The main objective of this work is to obtain a realistic and accurate method to evaluate the impact of Natural Light, as a function of their spatial and temporal location, using calculations involving geometric, photometric and climate aspects of the places where art exhibitions are located. This method makes easier the use of Natural Light as a primary or secondary source and, since it is a renewable energy, the need of artificial light, energy dependence and pollution can be reduced.

In order to evaluate the influence of Natural Light, our research has been developed in a permanent exhibition of 54 oils from Vicente Carducho painter, located in the walls of the fifteenth century cloister of the Monastery of Santa Maria de El Paular in Rascafría (Madrid, Spain).

Section 2 presents an empirical model to evaluate and predict the damage caused by daylight in this cloister. In section 3 the model proposed is applied and validated. Finally, in section 4 discussion and conclusions are presented.

2. Method for spectral evaluation of daylight damage in artworks

To date several studies concerning spaces illuminated by Natural Light propose methods to evaluate, use and control this type of illumination, or otherwise to avoid it [3–7].

In this research we present a methodology that quantifies the risk factor to which the artworks are exposed (defined and detailed in section 3).

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2.1. Previous

The cloister of the Monastery was renewed between 2007 and 2011. The purpose of the rehabilitation was to relocate the permanent exhibition removed some years before, due to its deterioration. The Institute of Cultural Heritage of Spain (Ministry of Culture) launched a project to recondition the cloister and to restore the oils previously exposed there. Curators and restorers from the Prado's Museum took over this work.

The project undertook several actions. The Natural Light was controlled through the use of filters installed on the windows. Those filters limit the incident radiation over the paintings, taking into account the cardinal orientation of the cloister corridors. The exhibition was opened to public in 2011.

After the reconditioning of the cloister, the Cultural Heritage Institute asked for the collaboration of the Complutense University of Madrid (UCM), specifically to get a detailed determination of the time and positions where the above work of art could be exposed. This collaboration allowed the managers of the Museum to stablish with objective data the optimal locations and dates where the paintings could be exposed. Useful information was provided to the restorers.

The study about the optimal value of radiation exposure on the artworks is based on the above references [8]. The research carried out by the UCM team, has taken into account the recommendations on how artworks should be illuminated [9,10]. The model characterizes the spectral composition of light and its intensity over time and space considering the geographic location of the cloister. The results were used in order to evaluate if the produced damage in the exhibition is under the criteria of conservation of restorer team.

A set of models has been developed to get a realistic measurement of the Natural Light effect on the artworks. The calculation includes a comprehensive and accurate estimation of the time-space variations. Values from the model have been compared with photometric data taken in the cloister along the last six years.

We have also analyzed in the calculation the influence of the responsivity of oil paintings (material used in the works), described by the model of Berlin [11].

According to the protocols on illumination in Museums [12] *UV* radiation has been neglected by using special glasses with filters placed in the windows whose physical characteristics are described in the following paragraphs. IR radiation was previously monitored and controlled with the temperature conditioning of the cloister. These actions were accomplished in the period of the cloister renewal. So, for the calculations carried out in this paper only radiation from 400–780 nm has been considered, range used by the CIE for the visible radiation.

The installation of glasses with filters of different transmittances (T) to control the radiation level was done by Saint Gobain Company. So, the *UV* radiation was removed and the visible light controlled. The characteristics of the glasses, according to the cardinal orientation, are specified in Table 1.

The transmittance measurements were taken with a SpectraPro-750,[1] Meter Triple Grating spectrophotometer Scan Range: 0–1400 nm mechanical range, accuracy: +/− 0.2 nm, Resolution: 0.05 nm at 435.8 nm.

2.2. Description of the models

In order to obtain an accurate evaluation of daylight it is necessary to define the main parameters which have influence in the final objective. Therefore, the next models have been used:

- Geometric-Photometric simulation.
- Spectral model of Natural Light.
- Spectral Damage model.
- Meteorological model.

The relationships between these models are shown in Fig. 1.

2.2.1. Geometric-photometric simulation

This simulation allows obtaining the illuminance values at each point of the cloister, along the year.

The geometrical part has been developed with a CAD program. This model is applied to specific software processing the photometric characteristics, with Dialux software [13], where the following aspects have been considered:

- Amount of radiation: Natural Light enters, depending on the cardinal orientation and the windows filters, on the located on the walls in front of the oils.
- Types of day according to the climate: clear day (A; no clouds in the sky), covered day (B; sky foul covered by close) and cloudy day (C; sky partially covered by cloud), and the type of radiation: direct and/or diffuse, according to the data provided by the National Institute of Meteorology AEMET in Rascafría (Madrid) that consider the average percentages of different type of days.
- The study was conducted from January to June, using equivalent illuminance values on 7th and 21st day of each month and at every hour of the day, from sunrise to sunset (more details in the spectral model described in 2.2.2).
- The values of the reflection coefficient used for the surfaces of the cloister, with were measured using a Stellar Net EPP2000[2] spectrophotometer (Scan Range: 200–1100 nm, resolution of the order of 1 nm), are: 20% for the soil, 70% for the ceiling; and 50% for the walls.

Since the interest of the study is only the vertical walls where the oils are exposed, only the illuminance values of these surfaces (whose dimensions are approximately 53 x 6.6 m) have been used to construct a 200 (horizontal) x 30 (vertical) matrix of equidistant points(distance between each point: 0.26 m horizontally and 0.22 m vertically). The sample value has been considered to be good enough for the objective of the research, and does not increase the computational requirements. Any of the matrix values corresponds to the value in *Lux* of the simulation for the same point.

In order to verify the values of the photometric model, illuminance measurements of the cloister were made using Luxmeter (Lux-Bug Hanwell,[3] Visible wavelength, 400–700 nm, Accuracy, +/− 1%, UV wavelength range Accuracy, +/− 1%) placed on the vertical face of the wall, taking a measurement every 15 min, 24 h a day, and every day since 2007 to 2013.

The sensors were placed 3.67 m above the floor of the cloister in period of the restauration (Fig. 2). This position was chosen because it is the area where Natural Light more affects the paintings. At the same time this height helps to keep safe the sensors of possible interactions with visitors.

Fig. 3 shows the measurements over six months in 2012.

2.2.2. Spectral model of Natural Light

The spectral characteristics and the amount of radiation of the Natural Light in Rascafría (Madrid), a very close village to El Paular, have been obtained (Fig. 4). Values of the sun spectral irradiance

[1] http://ridl.cfd.rit.edu/products/manuals/acton/old/MANUAL/Sp-750i.pdf.

[2] http://www.stellarnet.us/public/download/StellarNet-High%20Resolution%20Spectrometers.pdf.

[3] http://www.hanwellusa.com/pdf-conservation/LuxUVBug2USA3.pdf.