ILLUMINATION AND CONSERVATION: A CASE STUDY EVALUATION OF DAYLIGHT EXPOSURE FOR AN ARTWORK DISPLAYED IN AN HISTORIC BUILDING

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Abstract

This paper describes the application of climate-based daylight modelling to predict the annual daylight exposure received by an 18th century painting oil displayed on the Stone Staircase at Mount Stewart, near Belfast, Northern Ireland. The simulation predicted that the painting was receiving several times the recommended daylight exposure limit of 0.6 Mlux hrs for this type of artefact. The predictions were compared against the limited monitored data that were taken at the site. Notwithstanding the shortcomings of the monitored data, the agreement with simulation was sufficiently encouraging to allow recommendations to be made regarding interventions to help reduce the daylight exposure experienced by the painting.

Keywords: Daylight Exposure, Conservation, Climate-Based Daylight Modelling.

1 Introduction

This paper describes a case study evaluation of the cumulative annual daylight exposure of an 18th century oil painting, George Stubbs' *Hambletonian Rubbing Down* (1799-1800), which is displayed at Mount Stewart, near Belfast, Northern Ireland. The property is owned and managed by the National Trust who were concerned about the daylight exposure of the painting and wished to investigate methods of reducing its overall illumination, whilst still retaining satisfactory viewing conditions.

Due to its toplit location *Hambletonian* was illuminated at a level in excess of that recommended for conservation. Climate-based daylight modelling (CBDM) was applied as a novel method to investigate daylight exposure of the painting. The aim was to construct a daylight simulation that could be compared with measured illumination data and be used to investigate the impact of interventions to reduce daylight exposure. *Hambletonian* is hung on a staircase below a large, domed cupola at the top of which is a circular rooflight. Existing monitoring data from illuminance loggers and 'blue wool' dosimeters indicated that the painting was receiving several times the National Trust recommended annual exposure limit of 0.6 Mlux hrs.

The simulation study presented several challenges. Reliable daylight simulation of a real world setting requires a faithful 3D model of the enclosing environment (in addition to any significant external obstructions) and accurate values for the reflection / transmission properties of all the surfaces important for the transport of light. The creation of a suitable model for a heritage building can be particularly demanding. For the stairway at Mount Stewart the building geometry contained many circular and curved elements. Surface reflectivities had to be measured on site, as did the transmission properties for the rooflight glazing material. The practicalities for carrying out a suitable site survey for the daylight simulation of a heritage building are described in the paper.

2 Context for the daylight exposure study

2.1 Location

Stubb's *Hambletonian* is located on the west facing wall of the Stone Staircase at Mount Stewart. Above the staircase is a large oculus with a pyramidal glass roof. This ensures that the Staircase receives plentiful daylight and the painting is in a well lit location, one selected for visibility and impact by the Londonderry family before the painting and house were given to the National Trust. From the 1980s, concerns have been raised over the conservation of the painting and the National Trust has explored various means to control its daylight exposure and have monitored daylight over a number of years, under the assumption that the painting should remain in its current location.

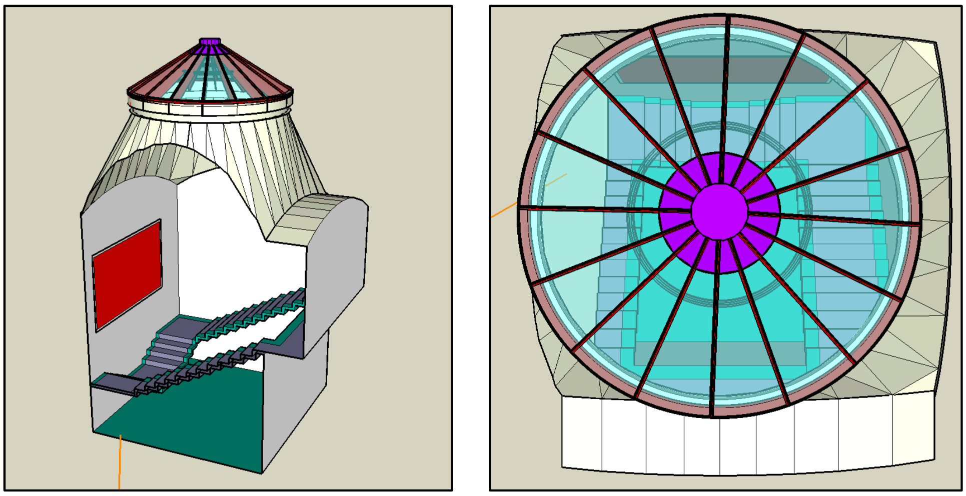

Figure 1 – 3D model of the Stone Staircase with the *Hambletonian* shown in red – section and plan view from above

2.2 Exposure, access and visibility

The National Trust has since the 1970s developed a daylight management strategy for the presentation of interiors and collections based on the number of hours of access by visitors and the responsivity of the materials displayed. Under the assumption that most properties are not open for more than 1,000 hrs a year and that most light sensitive materials should not receive more than a working limit of 50 lx, a maximum dosage of 50 klx hrs has been adopted. In areas with less sensitive collections and finishes this is 'relaxed' to the figure of 600 klx hrs adopted in museum collections, though with fewer hours of access the higher limit permits more flexibility in daylight levels. *Hambletonian's* location under a large roof opening has long been a source of concern and in the 1985 an adjustable louvre system was added to the exterior of the roof light to control daylight levels. This proved unmaintainable and was removed in 2005, since when the daylight on painting has been continuously monitored in anticipation of introduction of a new control system. As the Staircase is in constant use and the interior is Grade 1, the scope of options is limited, especially since the Trust wishes to maintain the visual impact of seeing the painting in its 'historic' location. Recent moves by the Trust to increase opening hours in its historic properties have focused attention how much daylight is admitted and how to optimise its use. In the case of *Hambletonian* there were already concerns that the painting receives substantially more than 600 klx hrs a year and the blue wool dosimeter measurements suggested several times this level of dosage.

2.3 On-site measurements

A variety of devices have been used to measure daylight levels and exposure adjacent to *Hambletonian*. These include blue wool dosimeters, used extensively by the Trust, and data loggers with cosine corrected sensors. The amount of data yielded by loggers is substantial and their use by the Trust is limited to testing areas identified at high risk such as *Hambletonian*. Due to field issues, the daylight data collected was episodic and required considerable processing to permit its use in comparison with data derived from simulation.

The two data loggers were placed on top of *Hambletonians* frame and the blue wool dosimeters attached to the lower right side. These locations are shown in Figure 2. From photographs taken it was found that one of the data loggers had been left tilted slightly upwards, raising expectations that it would record higher levels of exposure compared to the adjacent logger whose sensor was parallel to the plane of the painting. Given the relative position/orientation of the data loggers to the source of illumination (i.e. oblique from the rooflight), any discrepancy in data logger orientation is likely to result in noticeable differences in illuminance readings. The data received from the Trust was in the form of illuminance levels recorded hourly from the data loggers and cumulative exposures calculated from comparison of changes in the colour of the blue wool samples again calibration data, measured using a spectrophotometer (Bullock et al., 1999).

Figure 2 – Location of loggers and blue wool dosimeter adjacent to the painting

A review of the data revealed the episodic nature of its collection, with no full years either from the data loggers or from the dosimeters. This led to extensive review and more processing of the data from monitoring than was initially anticipated. In the case of the Blue Wool dosimeters, which ideally should be exposed either for a whole year or six months starting at a solstice, the data had to be normalised. This was undertaken using the results from a daylighting simulation for the interior using climatic data, which allowed for the year to be weighted on a monthly basis to allow for the substantial variations between summer and winter to be accommodated. A summary of the data collection periods and normalised annual dosages are given in Table 1.

Table 1 – Collected data periods and normalised annual doses

Location/type	Date range	Normalised annual exposure [klx hrs]
1 / Luxbug	Feb 2006 - Jun 2006	4,600
3 / Telemetric	Jan 2011 - Jun 2011	4,200
2 / Blue wool dosimeter	Nov 2007 - Oct 2008	7,000
	Nov 2008 - Jun 2009	1,900
	Oct 2009 - Feb 2010	1,600
	Mar 2010 - Jun 2006	2,200
	Oct 2010 - Mar 2011	5,300

The range of values derived from the blue wool dosimeters is substantial. Further investigation revealed that the blue wool samples used were exposed to beyond the calibration range employed by the Trust and, as a consequence, the annual dosage values derived were unreliable. In contrast, the two data loggers yielded similar annual dosage values, the value from the one at Location 1 being, as expected, slightly greater.

3 Simulated exposure and comparison with site data

The distribution in daylight exposure received by *Hambletonian* was predicted using climate-based daylight modelling (Mardaljevic, 2006). The data requirements and the daylight simulation are described below.

3.1 The building model

A 3D model of the Staircase was created in SketchUp based on a laser scanner survey of the interior carried out by John Meneely of Queen's University, Belfast. This provided an accurate set of dimensions of areas which would have been difficult to capture without erecting scaffolding. On site assessments were carried out to record the reflectivity of surfaces using the colour cards supplied with Lighting Guide 11 published by the Society of Light and Light and the National Physical Laboratory (CIBSE/SLL, 2001). These allow an estimation of diffuse reflectance within an error range of approximately $\pm 2\%$. The transmission of the existing glazing was tested using an illuminance meter, where a section of glass overhangs the perimeter of the oculus. The technique used was to measure the percentage reduction between the level incident on the glass and directly under the same spot. The glass in laminated with a PVB (UV absorber) opal diffuser interlayer. The near Lambertian performance of this material was confirmed by the National Trust staff at Mount Stewart who have observed no significant highlighting or brightness patches on the walls of the Staircase during periods of sunlight. The site visit also provided an opportunity to assess external obstructions. The only significant obstructions were the surrounding roofs, in all orientations. As these subtended less than 10° above the horizon it was decided to ignore them in the simulation.

The model was constructed in layers to allow differentiation of reflectivity values between surfaces and materials. Given the canyon like quality of the Staircase, no details were added to volume below the stair flights or the adjacent landing space as these were unlikely to have a bearing on the painting's accumulated light exposure.

3.2 Data on daylight availability

The principal sources of basic data for climate-based daylight modelling are the standard meteorological files. These locale/region specific datasets were originally created for use by dynamic thermal modelling programs (Clarke, 2001). They contain averaged hourly values for a full year for a range of meteorological parameters, e.g. temperature, wind-speed, etc. For daylight simulation the required parameters are diffuse horizontal illuminance and direct normal illuminance. Standard climate data for a large number of locales across the world are freely available for download from several websites. One of the most comprehensive repositories is that compiled for use with the EnergyPlus thermal simulation program (Crawley et al., 2001). This repository includes a dataset for Belfast (code IWEC 039170). The pattern of hourly values in the Belfast climate dataset is shown in Figure 3. The time-series data of 8,760 values for each of the two parameters have been rearranged into an arrays of 365 days (x-axis) by 24 hours (y-axis). The shading at each hour indicates the magnitude of the illuminance – see legend – with zero values shaded grey. Presented in this way it is easy to appreciate both the prevailing patterns in either quantity and their short-term variability. The patterns are unique and, because of the random nature of weather, they will never be repeated in precisely that way. Climate datasets are however representative of the prevailing conditions measured at the site, and they do exhibit much of the full range in variation that typically occurs. Furthermore, these standard datasets provide definitive yardstick quantities for modelling purposes. The dashed vertical lines show the start and end of British Summer Time.

3.3 Simulation of daylight exposure

Climate-based daylighting modelling can be used to predict both instantaneous and cumulative measures for luminous quantities, e.g. time-varying lux levels or long-term exposure in lux-hours. A cumulative analysis is the prediction of some aggregate measure of daylight (e.g. total annual illuminance) founded on the cumulative luminance effect of (hourly or sub-hourly) sky and the sun conditions derived from the climate dataset. It is usually determined over a period of a full year, or on a seasonal or monthly basis, i.e. predicting a cumulative measure for each season or month in turn. Evaluating cumulative measures for periods shorter than one month is not recommended

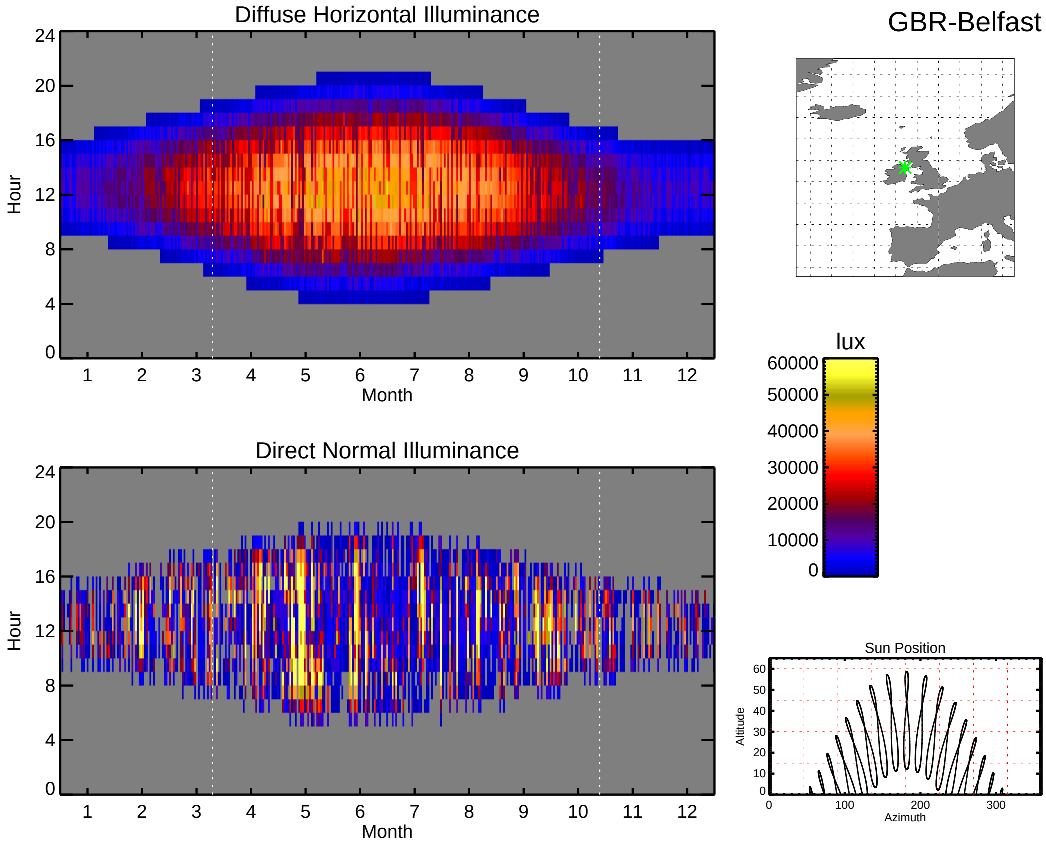

Figure 3 – Illuminance data for Belfast

since the output will tend to be more revealing of the unique pattern in the climate dataset than of 'typical' conditions for that period. Both cumulative and time-varying measures of daylight illumination were predicted for this evaluation, though only the former are presented in this paper.

For the simulation of cumulative daylight exposure, sky and sun descriptions that contain the aggregated contribution of all the unique hourly sky and the sun configurations were synthesised from the climate data shown in Figure 3. Separate luminance maps for the annual cumulative sun and the annual cumulative sky were generated in this way. The sky luminance pattern at each timestep was based on a blend of CIE clear and CIE overcast sky models depending on the Perez clearness index (Mardaljevic, 2008). The sky radiance at each of the 145 patches of the Tregenza pattern (Tregenza, 1987) was converted to the *Radiance* `brightdata` format using the method described for the validation of *Radiance* using measured sky scans (Mardaljevic, 2000). The `brightdata` luminance map for the annual sky was the numerical sum of all the individual timestep `brightdata` values from the blend model. Thus, in the simulation, the cumulative luminance sky was treated in exactly the same way as any standard sky brightness pattern (e.g. CIE clear sky), only the pattern was described using the `brightdata` type and the luminance at each point on the sky vault interpolated from the associated data file.

The radiation from the sun was modelled by considering all the possible sun luminance values / sun positions and aggregating their contribution into a set of 'binned' sun positions based on a regular grid in altitude and azimuth (Mardaljevic et al., 2003). Thus the *Radiance* description of the cumulative sun contribution was a scene file containing several hundred 'suns'.

4 Results

The predicted total annual illumination for the Stone Staircase is shown in a (cropped) 180° hemispherical fisheye view in Figure 4. Note, there was no attempt to match exactly the camera/lens view parameters for the simulated image. The approximate position of *Hambletonian* is indicated.

A photograph of the staircase from a similar vantage point is shown for comparison. The false-colour image reveals that the daylight exposure for *Hambletonian* is in the range ∼4,000 klx-hrs to ∼2,000 klx-hrs. A similar gradient in annual exposure is evident for the other two staircase walls.

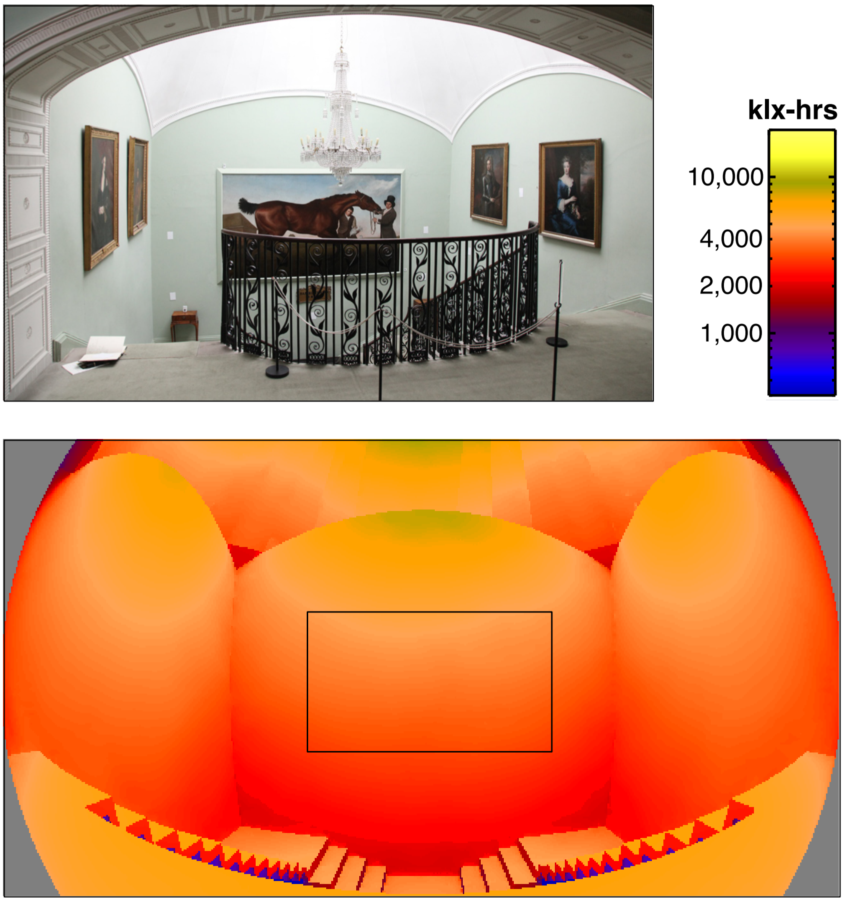

Figure 4 – Photograph of the Stone Staircase and predicted cumulative annual exposure

Figure 5 shows a close-up of the simulated exposure with the scale adjusted to better show the data in the plots. The painting area is divided into nine sections and each one is annotated with the average of annual daylight exposure in klx hrs. The simulation results showed that the painting was receiving between 2.8 and 4.4 Mlx hrs with an area-weighted average for the entire painting of 3.5 Mlx hrs. This is nearly six times the recommended value of 0.6 Mlx hrs.

Also shown in Figure 5 are the individual contributions from the sun and the sky to the total exposure. As expected from the Belfast climate data (Figure 3, the sun contributes rather less to the total exposure than light from the sky. The separation of the total daylight exposure into the sun and the sky components allows a test to be made regarding the assumption that the rooflight acts as a perfect diffuser. Table 2 gives the total annual illuminance from the sky and the sun received on an unobstructed horizontal surface, say, just above the rooflights. In parentheses are shown the percentage contribution to the total amount. Also given are the sun and sky components of the area-weighted average daylight exposure across the painting. For the climate data, the percentage contributions (to the total) from the sky and the sun were 75% and 25%, respectively. For the daylight received at the painting the split was 77% and 23% for the sky and sun components, respectively. These values are fairly close, indicating that the rooflight does indeed 'reprocess' incident light, whatever its direction, into diffuse that light enters the space below. If that were not the case, the ratio of the sky to sun components inside would be unlikely to match closely that outside. Note, the rationale for this would not hold if the rooflight did not have rotational symmetry around the zenith axis.

Table 2 – Sky and sun contributions to total annual illumination for the climate data (horizontal components) and at the painting

	Sky [lx-hrs]	Sun [lx-hrs]
Climate data	7.347e+07 (75%)	2.460e+07 (25%)
Painting exposure	2.715e+06 (77%)	8.19e+05 (23%)

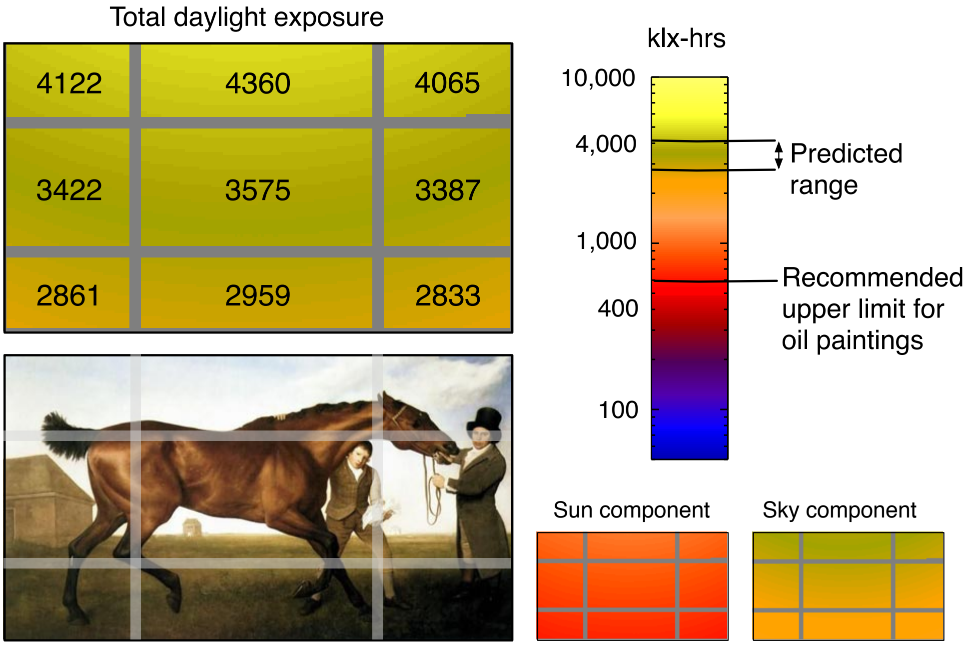

Figure 5 – Predicted distribution in cumulative annual illuminance across the painting

4.1 Comparison with measured data and suggested interventions

The simulated exposure value was compared with the measured values. For this it was necessary to estimate the contribution of missing data using interpolation as described previously. Notwithstanding the necessary limitations introduced by interpolation, the comparison between measured and simulated annual daylight exposure was encouraging. This gave confidence to proceed with the evaluation of various interventions to reduce daylight exposure that had been proposed by conservators and the project team at Mount Stewart. These included using lower reflectivity paints for the cupola and the staircase walls and reducing the effective transmission of the rooflight glazing with the complete or partial addition of a plastic mesh material.

These interventions were carried out in 2014. A photograph of the Stone Staircase with the lower reflectivity walls and cupola (and new frame for *Hambletonian*) is shown in Figure 6. Also shown is a view of the rooflight following the installation of an external mesh.

5 Discussion

The study reported here has shown that climate-based daylight modelling can be effectively applied to quantify and evaluate the exposure of sensitive cultural heritage to daylight. The effect of the interventions – principally, reduced reflectivity for the walls/cupola and light-attenuating mesh – is currently being evaluated and will be reported on in due course. In addition to simulating the effect of the interventions, it is hoped that further monitoring data will help to corroborate the findings.

Figure 6 – Photographs of the Stone Staircase and rooflight following the interventions

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