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Daylighting design with lightscoop skylights: Towards an optimization of proportion and spacing under overcast sky conditions

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ABSTRACT

The main aim of this article is to determine suitable proportions for lightscoop skylights, whose main characteristic is a vertical opening oriented in the opposite direction to the solar trajectory, with a view to ensuring maximum illuminance on the area under study within a room. Lightscape 3.2 software was used to carry out the simulations, comparing the results with those obtained using DaySim 3.1. It was finally concluded that for this type of skylight a height/width ratio of approximately 4/3 is the most suitable for ensuring the highest daylight levels in a room in overcast sky conditions.

1. Introduction and objectives

The use of skylights is frequent in modern architecture since they allow access to natural light in rooms lacking façades, while providing homogeneous lighting over the horizontal plane. Most researchers in this field have based their methodology on classic treatises on daylighting [1] and computer simulation.

Treado et al., among other authors, offered in-depth research on open skylights [2], analyzing their advantages and drawbacks. Among their conclusions they highlighted the fact that skylights are the most efficient openings in terms of daylighting, as an entire room can be adequately illuminated using 2% of the ceiling surface. They also concluded that lighting through skylights is more efficient than through windows, both for levels of illuminance and for uniformity. Subsequently, McCluney [3], basing his research on the analytical formulation developed by the IESNA [4] and on statistical data on the behaviour of skylights, created SKYSIZE, the first program for calculating daylighting and implemented in programmable calculators.

More recently Tsangrassoulis [5], using the method for flow transfer developed by Bouchet and Fontoynont [6], studied the efficiency of circular skylights and the amount of light these skylights allowed into a room. In 2003, the National Research Council of Canada developed SkyVision, a simulation program devoted exclusively to open or focal skylights [7]. This program is based on four description factors: optical characteristics of the glass panes, type of glazing assembly, calculation of daylighting using ray-tracing, and sky conditions as established by the CIE [8]. Despite the limitations in terms of types of skylight, since it only covers open skylights, the program obtains very precise results, as shown by Laouadi and Arsenault [9]. These results demonstrated the efficiency of this type of skylight, even in overcast sky conditions, while in clear sky conditions it is possible to obtain considerable thermal gains within the room. As a result, Laouadi [10] concluded that this type of skylight was ideal for cold climates with low solar radiation.

Lightscoops, with their characteristic vertical opening oriented in opposition to the solar trajectory, are frequently used in museum exhibition rooms, library reading rooms, etc. The term lightscoop should be further clarified, since this type of skylight has been described using a variety of architectural terms. Treado et al. define them as clerestories [11], and the CIBSE as monitors [12]. One of the most widely used definitions is provided by Lam [13], who terms them lightscoops if the opening is oriented towards the open sky, or sunscoops if oriented towards the solar trajectory.

Despite the fact that lightscoops are highly representative of contemporary architecture, few studies have been carried out on the luminous distribution they generate. Lam is one of the few authors to carry out in-depth studies on their behaviour for daylighting [14], concluding that lightscoops provide the lowest and steadiest light levels with minimum annual heat gain.

Among recent studies on lightscoops and sunscoops it is worth highlighting research carried out by García-Hansen et al. [15]. Using models on a 1:20 scale, with different models of skylight,

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the authors used nine photometers to study luminous distribution within the rooms. Using the level of illuminance measurements within the rooms, the authors deduced the thermal gains produced and consequently the Solar Saving Factor, which demonstrates the thermal behaviour of the skylight. The value of this factor shows the correct operation of this type of skylight, particularly for high latitudes. Despite the fact that numerous studies have shown the efficiency of this type of skylight, little attention appears to have been paid to the efficiency of the design in making the most of daylight.

The main aim of this study was to determine the most suitable height/width ratio in lightscoops in order to obtain higher illuminance levels within the spaces they light. Subsequently, a study was carried out on the most suitable distance required between lightscoops to ensure homogeneous lighting of the plan under study. This study followed preliminary research included in a published lecture presented at the 4th International Congress on Energy and Environment Engineering and Management [16].

2. Calculation methodology

2.1. Choosing the calculation conditions

Given that in this context a high number of variables preventing universal conclusions were introduced, the use of the clear sky hypothesis was ruled out. Analyses in overcast sky conditions are more advisable for comparing time variations as in these conditions uniformity coefficients and daylight factors remain invariable. The overcast sky model, used in all the trials, is that defined by Moon–Spencer [17], where the luminance values are distributed in accordance with the following law:

$$L_\theta = \frac{L_Z \cdot (1 + 2 \sin\theta)}{3}$$

where L_Z is the luminance at the zenith of the sky vault and θ the projection angle. This implies that the lowest luminance value in an overcast sky vault occurs on the horizon, and is equivalent to a third of the maximum luminance at the zenith:

$L_0 = \frac{L_Z}{3}$

The formulation established by Moon–Spencer corresponds to the definition of overcast sky accepted by the CIE [18].

Clear sky conditions always provide a greater luminance of the sky vault than overcast sky conditions [19]. As a result, if the calculation model meets expectations for overcast sky conditions, predictably it will also do so under a sky with greater luminance. However, in clear sky conditions the design of the skylight must avoid direct sunlight within the space. Lightscoop models avoid direct sunlight, opposing the opening to the solar trajectory, provided this trajectory follows a predominant orientation. These skylight models are therefore valid for locations north of the Tropic of Cancer and south of the Tropic of Capricorn. Nevertheless, at very high latitudes, lightscoops require vertical shading for shielding from low angle sun.

2.2. Choosing calculation programs

Two daylighting simulation programs were chosen to analyze the different skylight models.

The first of the programs used was Lightscape 3.2, which calculates luminous distribution using radiosity. The second program used was DaySim 3.1, which is based on the RADIANCE backward ray-tracer [20]. Several studies have confirmed the precision of these calculation programs [21–23]. Comparing the two provides more information for validating the results.

Table 1 shows the calculation parameters used by each program.

Table 1
Parameters of the calculation programmes.

Lightscape 3.2			
Sky conditions	Overcast sky		
Mesh spacing	Min		0.1 m
Max			0.2 m
Subdivision contrast threshold			0.65
Skylight accuracy			0.60
Source	Direct source	Min	0.12
		Subdivision accuracy	0.42
	Indirect source	Min	0.24
		Subdivision accuracy	0.42
	Shadow grid size		Five
Tolerances	Length		0.0005
	Ray offset		0.001
	Initialization min area		0.01
DaySim 3.1			
Sky conditions	Overcast sky		
Project climate file	Madrid.wea		
Grid dimensions	*X*	Start position	0.05
Grid size			8.90
Number of cells			40
	Y	Start position	0.05
		Grid size	8.90
		Number of cells	40
Radiance simulation parameters		Ambient bounces	5
		Ambient divisions	1000
		Ambient super-samples	20
		Ambient resolution	300
		Ambient accuracy	0.1
		Limit reflection	6
		Specular threshold	0.1500
		Specular jitter	1.0000
		Limit weight	0.0040
		Direct jitter	0.0000
		Direct sampling	0.2000
		Direct relays	2
		Direct pretest density	512

2.3. Choosing the calculation model

The initial model used for the trials was a room 9 m wide by 9 m long by 3 m high. A lightscoop, 6 m long and with variable height (*Y*) and width (*X*) (Fig. 1), was placed in the centre of the roof.

The model represents the typical dimensions of a museum or library room. The low height of the ceiling in relation to the measurements of the space allows a distribution of light that is largely dependent on the Sky Component and is therefore of use in analyzing the efficiency of the skylight proportions under study.

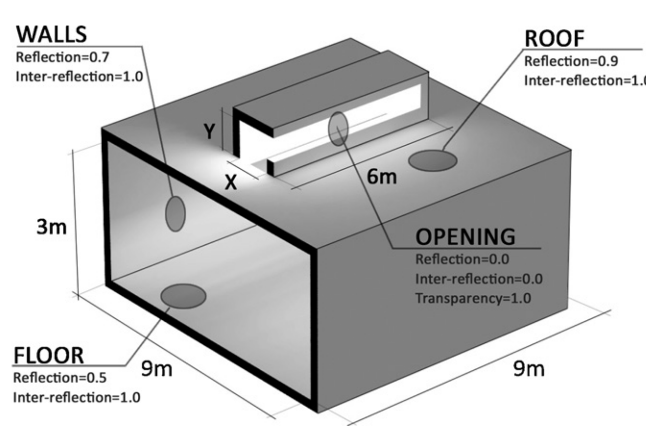

Fig. 1. Initial calculation model.