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The Experimental and Numerical Analysis of a Lightpipe using a Simulation Software

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Abstract—A lightpipe is an about 99 percent specular reflective mirror pipe or duct that is used for the transmission of the daylight from the outside into a building. The lightpipes are usually used in the daylighting buildings, in the residential, industrial and commercial sectors. This paper is about the performances of a lightpipe installed in a laboratory (3 m x 2.6 m x 3 m) without windows. The aim is to analyse the luminous intensity distribution for several sky/sun conditions. The lightpipe was monitored during the year 2006. The lightpipe is 1 m long and the diameter of the top collector and of the internal diffuser device is 0.25 m. In the laboratory there are seven illuminance sensors: one external is located on the roof of the laboratory and six internal sensors are connected to a data acquisition system. The internal sensors are positioned under the internal diffusive device at an height of 0.85 m from the floor to simulate a working plane. The numerical data are obtained through a simulation software. This paper shows the comparison between the experimental and numerical results concerning the behavior of the lightpipe.

Keywords**—**Daylighting, Desktop Radiance, Lightpipe.

I. Introduction

DAYLIGHT is believed to be essential both to provide a pleasant visual environment and to contribute to a feeling of wellbeing.

During the light hours when people work in a fixed position most of the time, the method of lighting is clearly crucial. Several studies demonstrate that when people work in entirely artificial conditions they are liable to illness and absenteeism. These problems can be overcame where the control system leads to a system of "daylight linking", in particular where the daylight penetration is combined to artificial sources. In this way the space appears to be daylighted during the day, even if some areas are supplemented by artificial light for some hours or for all day.

In this way the daylight is at the leading edge of solutions to human needs that must be satisfied [1], [2].

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II. Experimental Analysis

A. Set up

A lightpipe was monitored during the year 2006. It was installed on the roof of a laboratory. The laboratory is windowless and its dimensions are 3 m x 2.6 m x 3 m. The walls of the laboratory have different reflectance values: three walls and the ceiling have the reflectance of 66%, the south wall has the reflectance of 55% and the floor has the reflectance of 46%. In the laboratory there is a data acquisition system made up of a sensor connected to the HP 34970A. This sensor is put under the internal diffuser device at an height of 0.85 m from the floor and it measures the internal illuminance. There is another luxmetric sensor which is put outside the laboratory to measure the external illuminance values.

B. Data Processing

The internal sensor records the illuminance data every three minutes [5]. From these illuminance data the hourly average illuminance was calculated. The average day was introduced and elaborated to have a global vision of the internal and external illuminance behavior of the lightpipe under test, according to different weather conditions. The data processing was performed for all 2006. The illuminance value of the average day was used to develop the photometric curves of the twelve months. This study starts with a photometric hourly curve calculated as described in the next section.

C. Photometric Curve's Construction

The internal illuminance under the emitter was calculated as

$$E_{underemitter} = \tau \cdot E_{external} \quad \text{(lux)} \tag{1}$$

where $E_{underemitter}$ is the internal illuminance under the emitter, τ is the mean luminous flux transmission coefficient of the hollow guidance system (τ = 0.7) and $E_{external}$ is the external illuminance (lux) measured by the luxmetric sensor. Then the luminous flux Φ that comes out from the emitter was elaborated as

$$\Phi = E_{underemitter} \cdot r^2 \cdot \pi \quad \text{(lm)} \tag{2}$$

where $E_{underemitter}$ is the internal illuminance under the emitter, r is the radius of emitter. A support was built to measure the illuminance in the γ plane for the quadrant 0-90 degrees.

Through the Inverse Square Law, the illuminance intensity

I was calculated as

$$I = E_p \cdot d^2 \quad \text{(cd)} \tag{3}$$

where E_p is the internal illuminance measured by a luxmeter in a point of a plane perpendicular to the direction of the light incidence, d is the distance between the luminous source and the point of measurement. The illuminance intensity values were used to develop the photometric curves of the average day of a month [3] and then it was used as a model for the other months of the year 2006.

III. Numerical Analysis

A. Desktop Radiance

The Desktop Radiance is an advanced lighting software that optimizes the efficiency of daylighting systems and lighting technologies. It needs CAD drawings to provide the user interaction and 3D modeling capabilities. The first step in the process of performing a daylighting analysis is the creation of a 3D model that can be detailed appropriately using the Desktop Radiance library of materials, glazings, luminaries and furnishings. Then it is possible to use the analysis parameters such as camera views to obtain isolux and false color renderings and reference point calculations [4].

B. Data Processing

The lightpipe performance was modeled as an artificial lamp using Desktop Radiance. For each hourly average day of each month of the year 2006 a lightpipe model with the same photometric properties of the real model was elaborated. So at first was created a CAD model of the laboratory with the same reflectance property as the real one. Then a lightpipe model was created and it was introduced with its photometric curves in the Desktop Radiance's database. Later twelve lamps corresponding to the twelve average days of the year 2006 were created.

IV. Results

The simulations of the lightpipe's behavior were performed for the year 2006. In the Table I it is possible to see some external illuminance data measured by the external luxmetric sensor in some months of the year 2006 at 12 p.m..

TABLE I
Experimental External Illuminance (lux) at 12 p.m.

	Experimental External Illuminance (lux) at 12 p.m.
January	12247
February	32420
March	24350
May	52774
June	57363
July	63733
August	47963
September	45246

The illuminance sensors were put both on the floor and at a height of 0.85m to simulate a working plane to have a global vision of these natural light transportation system performances. In the Table II it is possible to see some illuminance results of some months of the year 2006 at 12 p.m. on the working plane.

TABLE II
Internal Illuminance on the Working Plane at 12 p.m.

	Internal illuminance on the working plane at 12 p.m.		
	Experimental data (lux)	Desktop Radiance data (lux)	Deviation%
January	49.68	47.26	4.87
February	71.59	68.95	3.69
March	74.33	70.77	4.79
May	287.29	272.7	5.08
June	496.47	465.66	6.21
July	471.46	448.47	4.88
August	129.46	122.96	5.02
September	112.26	106.75	4.91

During a month of summer (June) the maximum internal illuminance on the working plane was obtained at 12 p.m. both in the experimental (496.47 lux) and in the numerical results (465.66 lux) with a percentual deviation of 6.21. During a month of autumn (September) the internal illuminance on the working plane at 12 p.m. was 112.26 lux experimentally and 106.75 lux numerically with a percentual deviation of 4.91. During a month of winter (January) the minimum internal illuminance on the working plane at 12 p.m. was obtained both in the experimental (49.68 lux) and in the numerical results (47.26 lux) with a percentual deviation of 4.87. During a month of spring (May) the internal illuminance at 12 p.m. was 287.29 lux experimentally and 272.7 lux numerically with a percentual deviation of 5.08. The minumum percentual deviation between the experimental and the numerical results was obtained in the month of February and it was 3.69. The maximum percentual deviation between the experimental and numerical results was obtained in the month of June and it was 6.21.

In Table III it is possible to see the numerical results of the internal illuminance on the floor at 12 p.m.

TABLE III
Internal Illuminance on the Floor at 12 p.m.

	Internal illuminance on the floor at 12 p.m.
	Desktop Radiance (lux)
January	33.24
February	48.46
March	49.79
May	191.83
June	326.06
July	315.67
August	86.55
September	74.95

In the following figures, it is possible to see the isolux obtained by camera views in some months of the year 2006 at 12 p.m.. These figures show the behaviour of the lightpipe system and of its internal diffuser device according to the reflectance values of the laboratory. In Fig.1 it is shown the isolux for January. The highest illuminance value, which reaches a maximum of about 33.24 lux, is present in the middle of the floor under the internal diffuser device. The illuminance values decrease towards the walls.

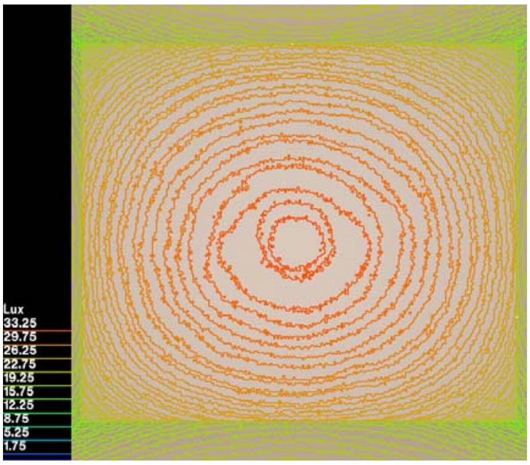

Fig. 1 The lightpipe isolux in January at 12 p.m

In Fig. 2, it is shown the isolux for March. The highest illuminance value, which reaches a maximum of about 49.79 lux, is present in the middle of the floor under the internal diffuser device. The illuminance values decrease towards the walls.

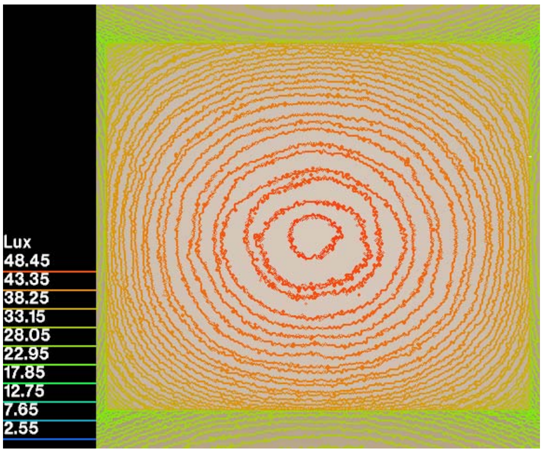

Fig. 2 The lightpipe isolux in March at 12 p.m

In Fig. 3, it is shown the isolux for June. In this month there was the maximum illuminance value (326.06 lux) in the middle of the floor under the internal diffuser device. The illuminance values decrease towards the walls as usual.

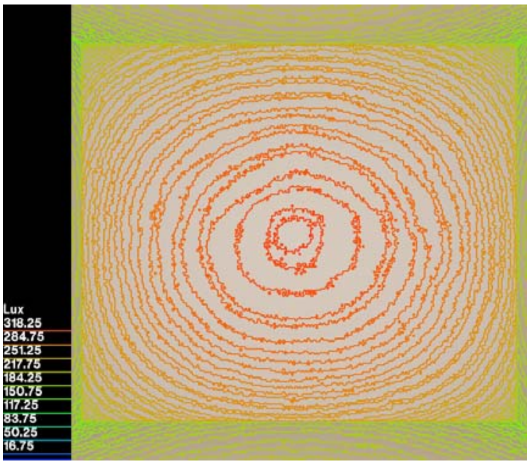

Fig. 3 The lightpipe isolux in June at 12 p.m

In Fig. 4, it is shown the isolux for August. The highest illuminance value, which reaches a maximum of about 86.55 lux, is present in the middle of the floor under the internal diffuser device. The illuminance values decrease towards the walls.

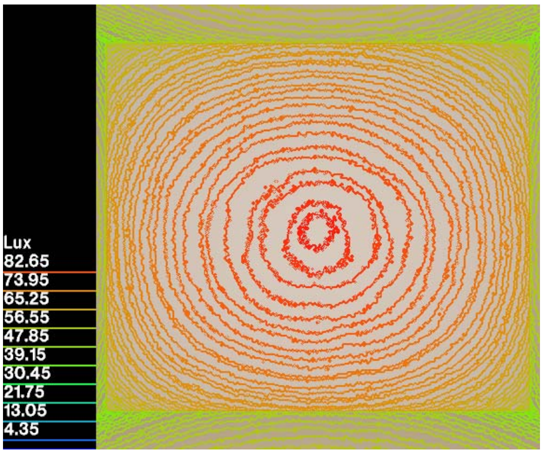

Fig. 4 The lightpipe isolux in August at 12 p.m

Daylighting design is a creative process. It aims to generate appropriate architectural and technical solutions to achieve an enjoyable and productive built environment while simultaneously reducing the energy buildings consumption through the substitution of daylight with electric light. Qualitative information and visual feedback on a given daylighting concept are usually as important for the building designer as the quantitative figures that reflect the engineering aspect of daylighting design.

In this research a database of the experimental internal and external illuminance values was created. This database was used to create some numerical models to simulate the lightpipe's performance during the year 2006.

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