

Numerical and experimental analysis on “Double Light Pipe”, a new system for daylight distribution in interior spaces.

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ABSTRACT: In this paper the authors illustrate an innovative system able to transmit daylight from the rooftop of a building, where natural light is intercepted, to hypogeal areas or rooms not equipped by windows and, contemporarily, to distribute daylight into the spaces passed through by the equipment.

This technological apparatus, named “Double Light Pipe”, has been studied into the Laboratory of Technical Physics of the Faculty of Architecture, University “G. D’Annunzio” of Pescara, Italy, where a numerical and experimental analysis has been carried out.

It consists of two concentric tubes: the internal one is a traditional light pipe, which transmits light from a clear collector commonly positioned on the roof top of the building, downward to underground areas where a polycarbonate diffuser is placed, while the external one lets light to enter into the locals that are positioned between the collector and the diffuser.

The numerical analysis has been carried out by ECOTECT and RADIANCE softwares and the obtained results are compared each to the other and with experimental data got by a reduced scale analysis.

Keywords: daylight, light pipe, double light pipe.

NOMENCLATURE

Symbol	Description [Units]
DF	Daylighting Factor
E	Illuminance [lux]
E_{ext}	External Illuminance [lux]
ρ	Reflection Factor
ϕ	Diameter [m]

1. INTRODUCTION

Daylight in architecture is more and more significant since it involves many aspects regarding visual comfort and energy savings that play a significant role in architectural design. Nevertheless an excessive use of

transparent surfaces, such as windows or skylights, is dangerous for generating thermal discomfort conditions in internal rooms, particularly in summer climate at latitudes typical of Southern Europe.

Light pipes play an important part to furnish the necessary amount of daylight into interior spaces, without significantly increasing the thermal load in summer. Traditional light pipes are able to introduce daylight in interior spaces without direct interface with sky or sun, such as hypogeal areas, or large plant area rooms, in which daylight from windows, positioned on boundary walls, doesn’t reach points on the work-plane far away from them. On the

other hand they are characterized by remarkable encumbrances and undesirable obstructions in the passage rooms between the captation point, commonly on the roof top, and the diffuser.

The idea developed in this paper is to propose an innovative system, named Double Light Pipe (DLP), consisting in two concentric tubes able to distribute daylight both in the final room, in which the diffuser is positioned, and in between zones traversed by the system.

The first internal tube is able to transport light away from the captation point like a traditional light pipe, while the second one, external and concentric to the first, made of a diffusing material, allows to introduce light into the passage spaces passed through by the system.

A model of the DLP was realized in a reduced scale (1:10) and it was experimentally tested. The results were compared with numerical ones obtained through some of the more commonly used softwares for simulation of daylight effects.

2. DESCRIPTION OF THE DOUBLE LIGHT PIPE

2.1 The idea

The idea of this new system is originated by the necessity to transform an obstructive device, such as a light pipe, into an architectonical element useful to distribute light in the midway ambient, positioned between the captator and the diffuser.

When a traditional light pipe is installed, light is captured on the rooftop of the building and transported to underground areas, passing through rooms not illuminated by the system and occupied by a very voluminous device. (e. g. Fig. 1-a). If a double light pipe is used, the system becomes an architectonic component which allows to furnish light both into the final local and the in-between one. (e. g. Fig. 1-b).

In a traditional light pipe a very reflective film is applied only over the internal surface of the pipe and the captator is a transparent surface with the same diameter of the pipe. On the contrary, in a double light pipe, the reflective film is applied on both internal and external surface of the inner pipe and a second larger pipe, concentric to the first one, is made of a transparent polycarbonate tube internally covered by a diffusing film. In this case the captator on the rooftop of the building is greater than the traditional, in order to partially introduce light into the inner tube and the remaining part into the outer one.

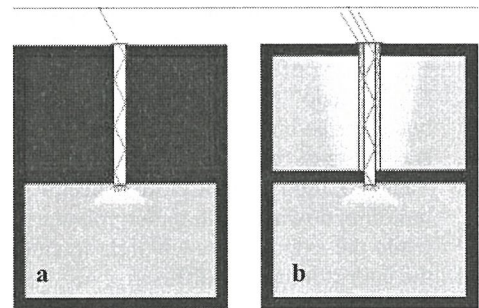


Figure 1: Comparison between a traditional light pipe and a double light pipe

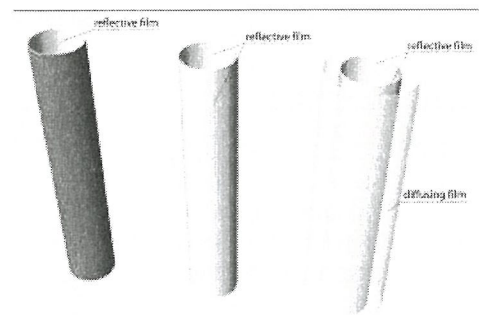


Figure 2: Evolution from traditional light pipe to innovative DLP

2.2 Description of the used materials

A multilayer highly reflective film both on its internal surface and external one covers the inner tube. It is characterized by a very high reflectivity coefficient ($\rho=99,5\%$)

and it permits to channel direct and diffuse light from the sky downward to the diffuser.

The outer transparent polycarbonate tube is internally covered by a thin diffusing material, called OLF (Optical Lighting Film) which distributes light into the passage locals. OLF is a thin flexible polycarbonate film with 90° micro-prisms applied on one side and smooth on the other side. OLF is commonly used to uniformly distribute natural or artificial light on a surface. In some applications, light from a point or linear source is spread by OLF, creating a perfectly diffusing surface light source.

It has good optical properties since it can simultaneously reflect or transmit depending on the angle at which a light ray strikes the film. If this angle is less than about $27,6^\circ$ with respect to the axis of the prisms it is reflected, while if it is greater than this value, it is transmitted.

3. EXPERIMENTAL ANALYSIS

3.1 Description of the model

A reduced scale (1:10) balsa wood model of a two levels building was realized in order to study the performances of a DLP. Each level consists of a 5x5 m plant area room, $h = 2,7$ m, and the DLP is realized by a $\phi = 30$ mm internal tube and a $\phi = 60$ mm external one. The external pipe is 3,0 m long and the internal one is 3,3 m long since it passes through the intermediate ceiling between the two levels. (e. g. Fig. 3)

Floor, boundary walls and ceiling are all made of unpainted balsa wood characterized by a reflection factor of about 50 %.

In both locals no window is present, so the DLP is the unique daylight source.

3.2 Experimental apparatus

Experimental analysis was effected measuring internal illuminance in two positions in the ground level (1,2) and four positions in the first level (3, 4, 5, 6), 0,5 m distant each to the other on a horizontal

work plane 800 mm high on the floor, as illustrated in Fig. 4 and 5.

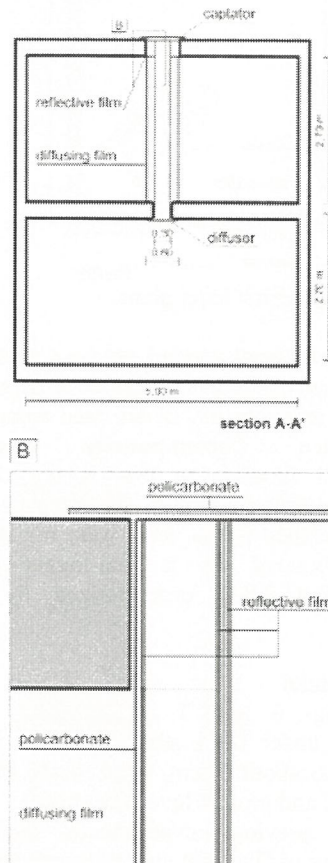


Figure 3: Geometric features of the model

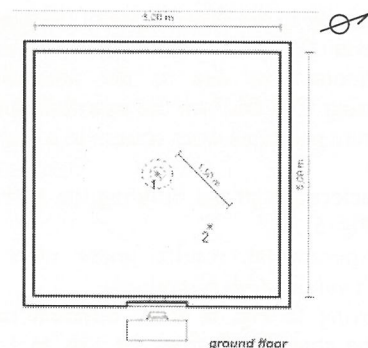


Figure 4: Ground floor plant

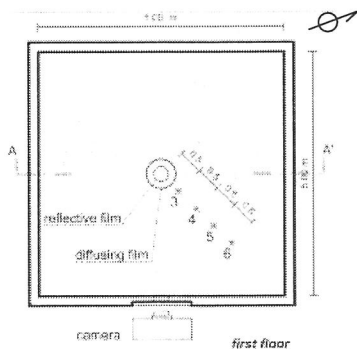


Figure 5: First level plant

Measures were carried out by CIE Luxmeters sensors type LSI-BSR001, range 0-25 klux, accuracy 3% of the read value for illuminance. Contemporarily external horizontal illuminance was measured by CIE sensors type LSI-DPA 503, range 0-100 klux, tolerance 1,5 %. Data were registered and elaborated by a data-logger type LSI/BABUC-ABC, characterized by 20 inputs.

3.3 Results

In Fig. 6 and 7 experimental data obtained under Clear sky conditions, from 10 a.m. to about 6 p.m., respectively in the first level and ground level, are shown.

In a previous experimental analysis carried out in Overcast and Intermediate sky conditions a good uniformity in illuminance values on the work-plane was obtained. It would be expected an analogous uniformity in the distribution of illuminance all over the work plane under Clear sky conditions too, due to the presence of diffusing film OLF on the external pipe. So measure positions were chosen in a way that takes into account symmetrical characteristics of the building. (e. g. Fig. 4 and Fig. 5).

Experimental results under clear sky didn't validate this hypothesis.

Referring to Fig. 6, three different ranges can be considered: from 10 a.m. to 1 p.m., during which a regular increasing trend of external illuminance is verified; from 1 to 2

p.m. with very irregular behaviour of external illuminance, varying between 35 and 95 klux, due to momentary climatic changes, and the last period from 2 to 6 p.m., during which a regular decreasing trend of external illuminance is verified.

During the first period a regular trend is verified of illuminance in positions 3÷6, decreasing from about 600 lux in position 3 to 250-300 lux in position 6.

In the third period three maximum values occurred in measure positions regularly distanced in time, 25-30 minutes one from the other: the first one at 2.30 p.m. in position 3, the last at about 4 p.m. in position 6. This is probably due to a particularly powerful direct component of solar radiation refracted by OLF that produces a more intense illuminance in all measure positions in turn depending on time variation of azimuth and elevation of sun.

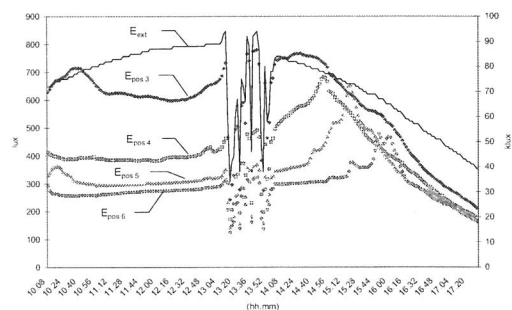


Figure 6: Experimental results – Clear sky, 1st floor

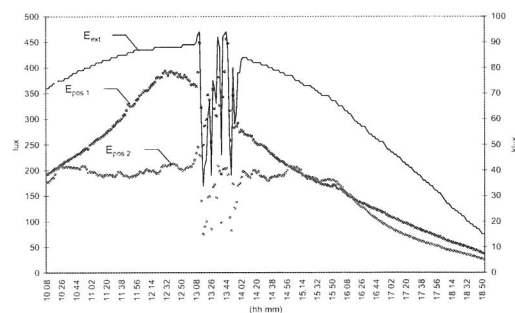


Figure 7: Experimental results – Clear sky, ground floor

Maxima are in addition verified in position 3 at about 10.30 a.m. and in position 5 at about 11 a.m. probably due to the same reason.

In Fig. 7 data on ground floor level are explained, in positions 1 and 2, in Clear Sky conditions, in which illuminance trend is strictly depending on external values, particularly in position 1 just under the pipe. Data in positions 1 and 2 are typical results obtainable by a traditional light pipe.

4. NUMERICAL ANALYSIS

Numerical analysis was effected by Ecotect and Radiance, two of the most reliable soft-wares in daylighting analysis. Ecotect produced data that are in good agreement with experimental ones. As an example, numerical results by Ecotect are shown in Fig. 8 and Fig. 9 in which numerical simulation is carried out at the beginning and quite the end of the test.

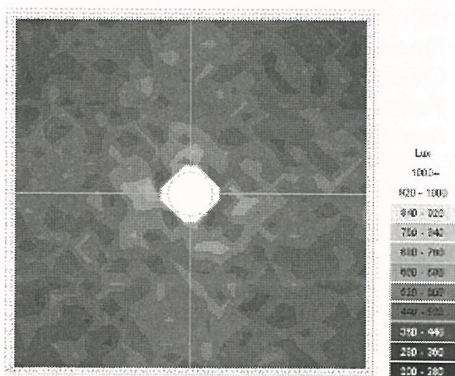


Figure 8: Numerical results by Ecotect – first level, at 11 a.m.

A comparison between experimental and numerical data by Ecotect is shown in Table I referring to the third period in which peaks in illuminance values are verified. A good agreement is obtained in all measure positions.

Finally a photorealistic rendering of the system under Clear sky conditions is shown in Fig. 10 obtained by Radiance.

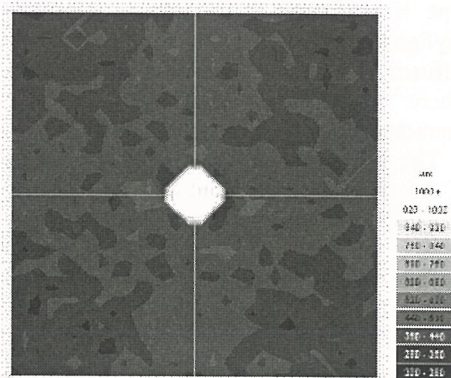


Figure 9: Numerical results by Ecotect first level, at 5 p.m.

Table I: Comparison between experimental and numerical data by Ecotect

h	2	3	4	p.m.
Pos 3-exp	678	687	516	
Pos 3-num	638	619	496	
Pos 4-exp	502	682	402	
Pos 4-num	505	627	421	
Pos 5-exp	350	532	384	
Pos 5-num	380	510	415	
Pos 6-exp	288	329	467	
Pos 6-num	310	301	448	

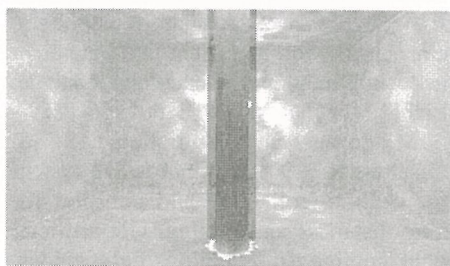


Figure 10: Numerical results by Radiance: photorealistic representation of the system in Clear sky condition

5. CONCLUSION

In this work an innovative daylight technological device, named Double Light Pipe is presented. It is able to distribute daylight both in final room where the diffuser is installed and in passage locals where traditional light pipes are characterized by significant encumbrances.

The experimental and numerical results of the analysis carried out by authors show that good performances are obtained in the passage room maintaining the same performances of traditional light pipes in final room.

The application of a diffusive film, named OLF, allows to realize a good uniformity of illuminance on the work plane with Overcast and Intermediate sky while with Clear sky in summer climatic conditions, in each measure position, maxima are verified equally distanced in time probably due to a particularly intense direct component.

Further analysis will be centred on OLF capacity to uniformly distribute daylight in all climatic conditions, since it seems very efficient with Overcast and Intermediate sky but not with Clear sky conditions too.

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