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Daylight in buildings equipped with traditional or innovative sources: A critical analysis on the use of the scale model approach

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ABSTRACT

The use of scale models is widely adopted as an efficacy method for determining the daylight assessment of interior areas of buildings. Scale models can be tested under real sky or sky simulators. In both cases, it is commonly accepted among the researchers that the use of scale models leads to an overestimation of experimental data with respect to real scale test rooms. Starting from this assumption, the authors have carried out an experimental analysis under real sky on a reduced scale model of a test room equipped with a window and on two scale models of a room equipped with a double light pipe in order to define the influence of the scale factor on experimental data both with traditional and innovative daylight sources. The analysis leads in particular to identify the influence of direct solar radiations on the results. Although the authors agree with the majority of researchers and confirm the common opinion that daylight performances are generally overestimated in scale model analysis, this study evidences that the presence of intense direct radiations can produce exceptions and the opposite case can be experienced.

1. Introduction

Daylight greatly influences indoor comfort and energy saving in buildings. Every activity is better carried out when natural light is available in the environment, even with lower illuminance than by artificial light [1–5]. Moreover, daylight significantly contributes to energy saving in buildings [5–7]. This is so true and important that, when natural light is not adequate, as in underground rooms or in large industrial and commercial areas, some technological devices can be used such as light pipes [8–10] or innovative daylighting systems as double light pipes [11–14].

Many authors have carried out their research in this field. Mayhoub [15] presents a broad overview of innovative daylighting systems (IDS), by classifying them into four categories: "The first includes the commercially available systems, the second includes systems developed but still under demonstration, the third includes systems in the prototype stage, and the fourth includes systems did not step beyond the theoretical idea".

In some cases, the daylighting systems are equipped with electric lighting sources to compensate for a possible reduction in the availability of natural light [16].

In this perspective, it is more and more important to define the real possibilities offered by the various methods of analysis in determining the daylight assessment of buildings.

The use of scale model approach is a common practise among the researchers [17]. This is probably due to its ability to do qualitative and quantitative assessments on the lighting performance of buildings.

Aghemo et al. [18] underline that "scale models are an efficient tool for modelling correctly spaces and to do photometrically correct analysis about daylighting performance", while Thanachareonkit et al. [19] argue that "despite the fact that the capability of computer modelling for daylighting was significantly enhanced in last decade, scale models still represent a standard method for the assessment of the daylighting performance of buildings".

Cheng et al. propose a simplified method in which the scale model experimental approach is combined with statistical analysis, allowing "...to grasp a right daylight strategy for general designers and users." [20].

Scale models of buildings can be tested both under artificial sky in different sky standard configurations or under real sky. Artificial skies allow carrying out comparative tests between models with different geometric and photometric features. This is easily accomplished using models with interchangeable parts. In this case, by taking advantage of the modularity of the model, different façade configurations or glazing surface dimensions, as well as various

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shadowing elements, can be tested and the results compared in order to assess the best daylighting performances obtainable in the real building [21].

If tests are carried out under real sky in various sky configurations, a more realistic representation of daylighting performance of building can be obtained and the influence of sudden variations of weather with different conditions of sky (overcast, cloudy, clear with or without sun. . .) can be taken into account.

The use of sky simulator leads to results that are free of errors due to climatic changes and appear more reliable. On the contrary, they are more affected by source errors, such as parallax errors or scale factor errors, due to the limited dimensions of the sky vault, which conditions the scale choice of the model. In this perspective, the maximum accepted dimensions of scale model are fixed to 1:10 of the diameter of the sky vault [21].

The use of scale models under real sky eliminates the parallax error, but it does not allow obtaining repeatable data.

According to [21], the choice of scale factor is a function of daylighting design purpose: very small scale models (1/500 to 1/200) are used for preliminary design development or to study the shadows from neighbouring buildings. Scale models ranging from 1/200 to 1/50 are useful for a coarse analysis of direct or diffuse light distribution in the space, while greater scale models (1/10 to 1/1) are useful tools for studying accurately light distribution in the space or for assessing the more critical and advanced daylighting devices or industrial components. Moreover, Kesten et al. [22] underline that different model scales are "commonly used for detailed façade (1:10), room (1:20) and building design (1:50)."

The majority of researchers agree that the use of scale models instead of real test rooms for daylighting analysis leads to an overestimation of assessed daylight performances [19].

Many authors evidenced the most relevant factors that influence these discrepancies, such as the geometrical or photometric parameters of the model, the features of sensors (cosine response, sensing aperture and shape) and the degree of precision in levelling and placement of them [23–25].

In compared tests between real scale and reduced scale models, it is also very important the alignment of models, in order to have the same sky view factor as underlined by Thanachareonkit et al. [19]. As highlighted by Yun et al. [26], the outside view from a scale model is very similar to that of the real scale room if the model is located in front of the window of the room. Thanachareonkit et al. [19] moreover highlight that the mocking up of surface reflectance has a very strong impact on scale model accuracy in detecting daylighting performance of buildings. Low discrepancies of the reflection factor lead to major illuminance and daylighting factors in reduced scale model respect to real scale models and higher discrepancies occur in measure points very distant from the window. In the same work, the authors emphasize that a significant error in overestimation of scale model assessment of daylighting performance is due to photometric properties and cosine response of different lux-metric sensors.

So far, it has been given little importance to the influence of direct solar radiation on the behaviour of scale models, but it is very significant overall in summer condition and its influence cannot be neglected, overall when daylighting performance of buildings is evaluated by comparing experimental data on scale model and real test room.

In this work, the authors show the results of an experimental activity carried out under real sky and sky simulator on some reduced scale models of buildings equipped with windows or technological devices for daylight, such as the double light pipe. The last is a transport system of natural light set up by the authors for daylight transmission in a double level building. Unlike what happens with traditional light pipes, the double light pipe is able to illuminate both an underground room, and simultaneously the passage room in which it is installed. An accurate analysis of this device is given in [11–14].

The authors compare data collected in some scaled models of building in order to emphasize certain standard behaviours and some anomalies that occur with scale model analysis. They have considered four cases, as specified in chapter 3. In the case of the model equipped with window, the comparison is carried out with a real scale room. A particular emphasis is given to the analysis of the influence of direct solar radiations that are particularly intense in summer condition.

2. The double light pipe

The double light pipe (DLP) is an innovative device developed by the authors to illuminate a two-level underground room. This system allows the natural light transmission in underground rooms, illuminating, at the same time, the passage areas that have to be crossed by the system. Fig. 1 shows a reduced scale model of the system and its illuminating function in the passage and final room.

The double light pipe consists of two concentric pipes: the inner one is covered on both the internal and external surfaces by the same multilayer film which is characterized by a very high

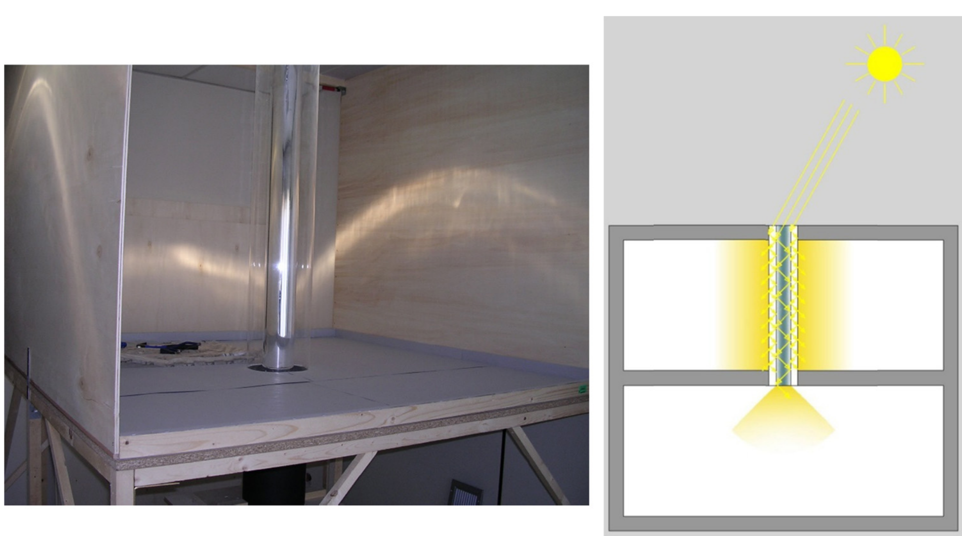

Fig. 1. The 1:2 scale model of the double light pipe and its illuminating function in the passage and final room.