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RESEARCH ARTICLE

Verification tests of a mirror box type artificial sky without and with building scale model

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Abstract
A mirror box type artificial sky for simulating the CIE standard overcast sky has been designed and constructed, while the verification method has been developed and tested. Ratio between the mirror height above the workplane and the room length is 60:133 or 0.451, whereas the ratio between the mirror height above the workplane and the room width is 5:9 or 0.556. Taking the CIE standard overcast sky as reference, indoor illuminance ratios at various elevation angles relative to the zenith is found to be more consistent than luminance ratios. The largest error of illuminance and luminance ratios are respectively 10% and 43%, obtained at 0° elevation angle. Horizontal workplane illuminance values are on average 11,400 lx, with illuminance uniformity U_0 and U_1 of respectively 0.92 and 0.86. Based on test results with a building scale model, four out of nine measuring points inside the model have small errors, four have medium error, and one has a large error of 25%. Most of the obtained errors are within the tolerable range of ± 21% from the ideal values. Based on the conducted tests, the constructed mirror box type artificial sky is considered appropriate to be utilised for its purpose.

1. Introduction

In the context of building design, daylighting is one of the important components that positively contribute to sustainability and energy efficiency. Many researchers have shown that admission of daylight through openings such as

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windows in buildings give positive effect on health and well-being of the occupants. Optimum use of daylighting can also effectively reduce electrical energy consumption particularly from the artificial lighting. Since daylight in reality is constantly changing, a number of (mathematical) sky models have been proposed and adapted in standards and building codes as reference for predicting daylight performance of an interior space, particularly during the pre-design stage of the building.

While direct calculation and estimation methods and formulae are available, there are cases in which the room geometries and/or fenestrations are too complex. In this case, modelling and simulation technique is preferred, using either physical or computational model. The latter becomes increasingly more popular nowadays, owing to its flexibility and efficiency. However, the use of physical (scale) model in daylight performance prediction has still somehow got its place in giving a better sensation and understanding of the context, particularly for educational purpose in schools of architecture and/or building science. Moreover, with scale models, not only complex geometries can be analysed, but simple modifications of the geometry can be made with interchangeable parts (Pereira et al., 2012).

In daylighting studies, once a scale model is chosen to represent a space, it should therefore be placed under a real sky or an artificial sky. For the former case, Mardaljevic (2002a) have shown that errors in scale model under real overcast sky were over 50%, whereas under real clear sky, the errors can be as large as 100%–250%. Under real skies, there is a large variability not also in terms of exterior illuminance, but also in terms of luminance distribution of the sky itself, leading to a large departure from the mathematical sky model.

As an alternative, artificial skies have been employed as an analogical simulation tool (Dubois et al., 2015) for predicting daylight performance in scale models, since many aspects of the environment can be controlled and standardised. In general, there are two types of artificial skies: hemispherical and rectangular. The former is employed to simulate the clear and intermediate skies, in which the sky luminance distribution can be controlled by varying the luminance of (many) individual lamps constructing the hemisphere. A hemispherical artificial sky normally requires a large round space of 6–8 m in diameter (Szokolay, 2008), thus requiring a relatively high construction cost. Many laboratories and schools of architecture however have built this type of artificial sky for research purpose (e.g. Kittler, 1974; Selkowitz, 1981; Stupple et al., 1989; Lioutsko and Spiridonov, 1992; Michel et al., 1995; Mardaljevic, 2002b; Bodart et al., 2006).

The latter form of artificial sky, the so-called mirror box type artificial sky, has a limited function as simulator of the CIE standard overcast sky, but is easier to construct due to its relatively simple design. Typically, a number of tubular or strip lamps/luminaires are placed on the ceiling of the rectangular room, and a layer of diffuse translucent material is placed beneath the luminaires to diffuse the light throughout the room. The room walls are covered with plane mirrors, usually up to the workplane height, to create inter-reflection while giving the spatial perception of an infinite horizon. To avoid reflection from below the mirrors, the lower walls are usually painted black or covered with black matte material. Despite its simplicity, there are not many scientific reports on testing and verification of mirror box artificial skies. Few examples (though not all of them are publicly available) are Coosky et al. (1989); Bouten and Rutten (1995); Matusiak and Arnesen (2005); Pereira et al. (2012). In those mentioned examples, verification tests were mostly performed either in empty room condition or inside a scale model under the artificial sky, but rarely both. This study therefore focuses on both types of verification tests, conducted in a newly constructed mirror box artificial sky. In order to conduct a proper verification test, mathematical models of the overcast sky and the daylight availability metrics shall be revisited and kept as reference.

1.1. Mathematical model

The standard overcast sky was originally proposed by Moon and Spencer (1942), which were later adopted by the International Commission on Illumination (CIE, 2003; 2014) and is still applied nowadays to describe a hypothetical version of the worst case scenario in which the sky is covered with thick clouds without any visible patch of the sun. In this model, the sky vault luminance (Fig. 1) observed at a given elevation angle θ, L_θ [cd/m^2], is empirically related with the zenith luminance ($\theta = 90^\circ$), L_z [cd/m^2],

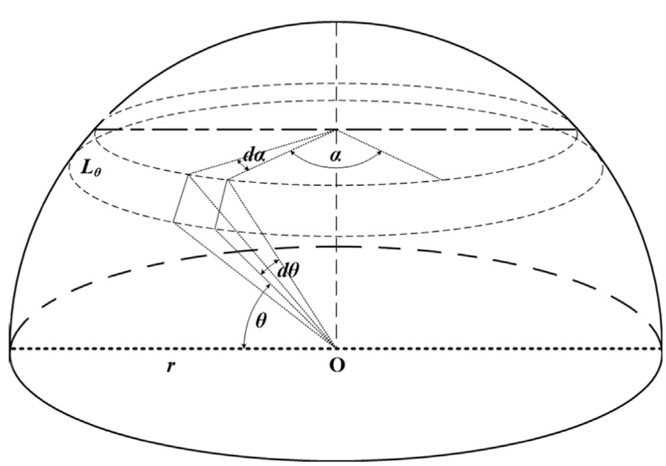

Fig. 1 Illustration of sky vault in the CIE standard overcast sky model.