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Validation of the Belgian single-patch sky and sun simulator

M. Bodart[a,*], A. Deneyer[c], V. Gilbert[b]

[a]Postdoctoral Researcher Fonds de la Recherche Scientifique-FNRS Université Catholique de Louvain, Unité d'Architecture, Place du Levant, 1, B-1348 Louvain-la-Neuve, Belgium
[b]Université Catholique de Louvain, Unité d'Architecture, Place du Levant, 1, B-1348 Louvain-la-Neuve, Belgium
[c]Department of Building Physics and Equipments, Belgian Building Research Institute (BBRI), Avenue Pierre Holoffe, 21, B-1342 Limelette, Belgium

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Abstract

This study considers the validation of the Belgian sky and sun simulator that uses the daylight coefficient method to predict illuminance in architectural scale models. The validation work includes comparisons between the measured and the calculated illuminance values for CIE overcast skies, for a CIE clear sky without sun, and for the sun alone. The measurements were made in a simple rectangular scale model and the numerical simulations were carried out by Superlite and RADIANCE. The comparison of mock-up measurements under the single-patch sky simulator (SPS) and the mirror box (MB) to RADIANCE predicted values produced low-root-mean-square errors (RMSEs) (with a maximum RMSE of 17.5% for the simulator and 22.7% for the MB) and low positive mean bias errors (MBEs) (maximum values of 8.5% and 13.3%, respectively). Although the sun patch size was slightly overestimated, especially at low-sun altitudes, the results were reliable and in accordance with the sun simulator's objectives. Parallax error measurements were undertaken, and these led to a restriction of the model size in order to limit the error to 12.5% for a CIE overcast sky.

Keywords: Daylight; Sky simulator; Sun simulator; Scale model; Validation

1. Introduction

Scale models have been used for daylighting evaluation for many years [1]. They can be illuminated by the real sky and sun or more commonly, for convenience and standardisation, by artificial skies [2]. Today, even though computer simulations can give very accurate results in a reasonable time, our experience indicates that it is essential for architects to personally appreciate the luminous qualities of a space and to compare several solutions quantitatively and qualitatively. This intuitive appreciation, which is obtained from scale models and the three-dimensional perception of the light distribution, cannot currently be obtained by the use of computer simulations.

The Architecture Department of the Université Catholique de Louvain (UCL) and the Belgian Building Research Institute (BBRI) have decided, with the support of the Belgian government, to encourage the use of daylight in buildings, and therefore, to provide architects and building designers with tools that could help them to improve the penetration and distribution of natural light in their buildings. To assist with this, a new single-patch sky and sun simulator has recently been designed in Belgium [3]. This simulator is based on the daylight coefficient method [4] and models one patch of the Tregenza sky subdivision [5]. The sky patch is made by 91 halogen lamps placed according to a hexagonal array and fixed on the laboratory ceiling. The distribution of the complete sky dome is recomposed by rotating the scale model 145 times around two orthogonal axes. Illuminances and luminances, as well as images are computed and generated by data processing [3].

The choice of a single-patch sky simulator (SPS) instead of a full-hemisphere sky simulator dome was made following a review of existing sky and sun simulators [3]. This review shows that the SPS has many advantages over a full-hemisphere sky simulator dome. The chief among these are its low construction and utilisation costs, limited calibration procedure, easy control of the lamp flux

*Corresponding author. Tel.: +32 10 47 91 52; fax: +32 10 47 21 50.
E-mail address: magali.bodart@uclouvain.be (M. Bodart).

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variation, and the limited area required for installation, allowing a greater apparent diameter of the dome.

An additional advantage of the single-patch sky concept is that it is possible to weight the flux from each patch independently from 0% to 100% as there is no dimming of the lamp. Every type of sky can thus be modelled, which is not the case for all sky simulator domes, depending on the type of lamp. Moreover, as the simulator is based on the daylight coefficient method, it is suitable for the prediction of the annual daylight profile, based on hourly meteorological data.

The main disadvantage of the SPS is that direct view and measurement in the model are not possible, as they need to be computed from 145 measurements, whatever may the sky type be. Moreover, as daylight factor remains the most widely used performance measure for daylighting and majority of practitioners, it was decided to provide to architects and students in architecture, a simple tool for evaluating the daylight factor in their models. A mirror box (MB) was, therefore, used as a complement to SPS. A MB consists of a luminous ceiling with mirrored walls. The light source is a white diffusing material illuminated by lamps from behind. The mirrors, arranged vertically all around the periphery of the box, produce an image of the lit ceiling by reflection and inter-reflection to infinity. The sky-light distribution corresponds to that of a CIE overcast sky [3].

Having built the MB and the SPS, it was necessary to evaluate the precision of the results obtained by these laboratory devices. The objective was to compare the simulator's accuracy to that of existing sky simulators. Despite the existence of several artificial skies and suns all over the world [1], very little validation work has been published. To our knowledge, the only published validations are those of Selkowitz [6] and Spitzglas et al. [7] who made comparisons between outside measurements and artificial sky measurements, and between artificial sky measurements and Superlite simulations, but did not calculate any statistical indicator of the accuracy of their devices.

The validation work presented here focused on comparisons between scale-model measurements and software simulations. Measurements and calculation comparisons were made in a simple box mock-up to evaluate the measurement precision in the MB and the SPS. For overcast sky, measurements were made both in the MB and under the single-patch simulator. For clear skies, measurements were only made with the single-patch simulator as the MB cannot model clear skies. These measurements were compared to the simulation results from the RADIANCE simulation programme [8], which is considered as the daylight reference programme [9]. Additional simulations were made with the Superlite simulation programme (SUP) [10] to evaluate the accuracy of this programme and to compare it with the accuracy of the sky simulator results.

Section 2 of this paper describes the validation mock-up geometry and all the facades tested as well as the measurement devices, while the metrics used for the statistical analysis and the notations used in this paper are summarised in Section 3. Sections 4–6 are dedicated to the validation results for the CIE overcast sky, the CIE clear sky without the sun, and the direct sun. Section 7 presents the parallax error measurements and calculations. Section 8 discusses the origins of errors and possible extensions to our study by comparing mock-up measurements to full-size room measurement, and Section 9 summarises our findings.

2. Scale model and measurement devices

The scale model we tested, which represents a virtual office room at 1/10 actual size, is a parallelepiped of $0.305 \times 0.305 \times 0.655\,m^3$. The south oriented small lateral facades is divided into 9 identical squares that are either opened or closed, to test 27 different configurations. In addition, two configurations of zenithal openings were tested. Fig. 1 shows three lateral and one zenithal configurations, as examples. Fig. 2 shows the 27 lateral facade configurations and Fig. 3 the two zenithal configurations.

The ceiling, walls, and the floor of the model were covered with cardboard, respectively, of 80%, 60%, and 37% diffuse reflectance. The illuminance values were measured by 13 illuminance meters placed at work plane height (0.8 m at full scale), facing upwards. They were placed along a central axis, perpendicular to the window facade, at 50 mm from each other. The sensor's positions in the model are presented in Fig. 4a. Two additional sensors were placed on the roof of the model to measure the horizontal unobstructed illuminance.

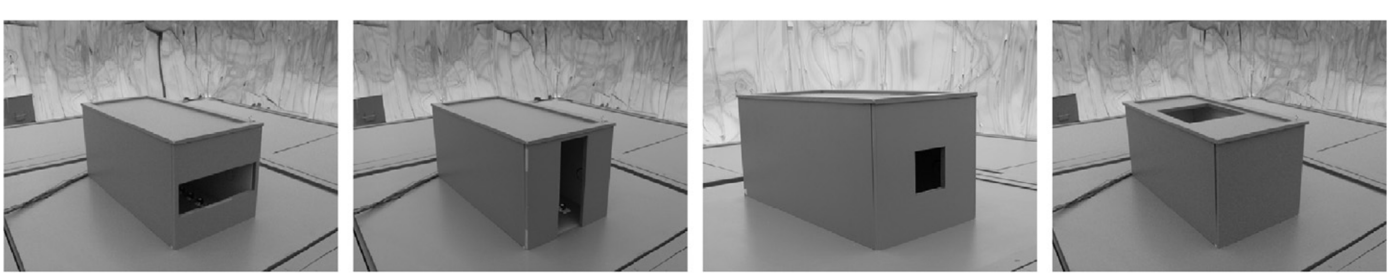

Fig. 1. The mock-up with four different facade configurations.