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Analysis of the accuracy of the sky component calculation in daylighting simulation programs

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Abstract

The main aim of this article is to analyze the precision of several lighting simulation programs regularly used in daylighting studies for architecture, following the methodology established in the CIE test cases document. The 3DS Max Design 2014, Daylight Visualizer 2.6, DaySim 3.1b, Design Builder 3.0, Dialux 4.8, Ecotect Analysis 2011, Lightscape 3.2 and Relux Pro programs are analyzed. In order to establish the precision for each program, the sky component is measured at different points of study on the floor of a room, taking variable sizes and positions of openings into consideration. The results are contrasted with the analytical calculation of the sky component using Tregenza algorithms and the test cases established by the CIE, considering the models for Traditional and Standard Overcast Sky. Following the analysis of the sky component using the CIE test cases, it is concluded that the 3DS Max Design 2014 and Daylight Visualizer 2.6 programs present a maximum relative difference from the analytical model of close to 10%, while the DaySim 3.1b, Dialux 4.8 and Lightscape 3.2 programs show a margin of relative error lower than 30% in all case studies. Design Builder 3.0, Ecotect Analysis 2011 and Relux Pro show inadequate results.

Keywords: Daylighting; Lighting simulation; Overcast sky; Test cases

1. Introduction and objective

1.1. State of the art

Introducing effective daylight strategies has become an essential goal for any sustainable building. However, since it is difficult to evaluate daylight quality and quantity in non-standard spaces using manual methods, the use of daylight simulation has considerably increased as a necessary step toward the accurate evaluation of daylight in buildings in order to help designers or decision makers to choose appropriate architectural and/or technical solutions to achieve a comfortable built environment. Lighting simulation is increasingly becoming a substitute for traditional verification techniques (Ibarra and Reinhart, 2009; I.E.A. S.H.C., 2005; Ochoa et al., 2012; Estes et al., 2004).

For the last two decades, the use of computer lighting simulation in building science has been widespread, although the development of natural lighting simulation tools dates back to the 1970s (Ochoa et al., 2012; Shi and Yang, 2013; Kota and Haberl, 2009). Computer programs are continuously modified, some of them fall into disuse and others supersede them or update their algorithms to guarantee greater accuracy (Estes et al., 2004).

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Given the great number of simulation models available, numerous evaluations have been published. These can be divided into two groups: comparisons based on replicating a built reality (scale models or reality), and comparisons in controlled laboratory settings (Ochoa et al., 2012; Estes et al., 2004; Maamari and Fontoynont, 2003), although it is difficult to compare the results obtained using each individual method. In addition, lighting simulation tool comparisons have been widely published to help lighting designers choose the most suitable program, and standardized comparison methods have been developed (CIE, 2006; Reinhart and Breton, 2009). These comparison methods are usually carried out by simulation experts (Ibarra and Reinhart, 2009; Iversen et al., 2013), whose knowledge about daylight and the underlying algorithms is much higher than self-taught new practitioners.

The growing use and interest in daylight simulation tools can be attributed to building standards and, most of all, to green building rating systems (Ibarra and Reinhart, 2009). A number of surveys were carried out in the past regarding the use of building simulation tools during building design. In 1994, almost 77% of participants in a survey used both computers and physical models for their professional practice. By 2004, participants who used no daylight prediction software had dropped to 21% (Reinhart and Fitz, 2006). This percentage may be reduced even further as architectural and engineering students become increasingly familiar with computer modelling throughout their education (Ochoa et al., 2012).

Most building design practitioners and students who are currently building three dimensional CAD models are using their models to visualize their designs for qualitative analysis and client presentation purposes (Reinhart and Breton, 2009). On occasion, newcomers do not have expertise in daylighting, while novice users are confident that their results do not differ drastically from those of expert users, although some studies have reported the discrepancy between non-expert and expert user results (Ibarra and Reinhart, 2009).

This paper presents a study of the accuracy of several simulation programs, some of them specifically developed for daylighting analysis and others for architectural design, artificial lighting, energy analysis or whole-building conceptual design, widely used in practice, and incorporating daylighting analysis modules exclusively on the calculation of the sky component, which represents the daylight factor produced only by the sky vault, using the corresponding CIE Test Cases (CIE, 2006). It also presents the discrepancy between the default value results given by these programs, mainly used by novice users, and the validated value results given by expert users for validation reports.

1.2. Daylighting simulation and tools

Modern physical models explaining light transport in all types of media are too complex for computer calculations and image generation (Ochoa et al., 2012). A simplified model of geometrical optics and energy conservation, from which physical formulas are established, is used instead. However, differences between measurements and simulations in specific modelling contexts might be accounted for by these simplifications, particularly when diffusing or refracting media are involved (Ochoa et al., 2012).

A large number of different program interfaces is currently used, but the underlying simulation algorithms concentrate on a limited number of approaches. These can be classified into three types: direct calculations, view-dependent algorithms and scene-dependent algorithms. The two most popular in use today are ray-tracing and radiosity, although other scene-dependent algorithms, known as integrative approaches (such as the photon map), have been developed (Ochoa et al., 2012; Estes et al., 2004; Iversen et al., 2013; Reinhart and Fitz, 2006). Specifically, the radiosity process is a scene-dependent algorithm, regardless the point of view. On the other hand, the ray-tracing process is a view-dependent algorithm.

The inclusion of daylight analysis in energy tools is not new (Kota and Haberl, 2009; Berkley National Laboratory, 2012); some studies have reported how energy and daylight analysis could be coupled (Yun and Kim, 2013; Ramos and Ghisi, 2010). The use of energy simulation programs for daylight analysis is of growing interest as one model could give different performance building aspect results, thus saving time on building different models using different programs.

The international implementation of green building standards such as LEED or BREEAM, which establish many quantifiable performance requirements for the guidance and control of architectural design, is encouraging performance-driven design, bringing more rational thinking and scientific analysis, such as Daylighting Analysis, into the field of architectural design (Shi and Yang, 2013).

Performance-driven architectural design emphasizes an integrated and comprehensive optimization of various quantifiable performances of buildings. Compared with conventional architectural design methodology which focuses on space form, performance-driven design takes a holistic view of ecological and environmental performance of buildings while ensuring that the functions and aesthetics of the design are not overlooked (Shi and Yang, 2013).

1.3. Software validation tests to assess daylight accuracy

A number of computer software programs exists which model the distribution of light inside a building. A literature search revealed a number of papers comparing various software packages and computation methods. Experience has shown that results for the same room, obtained from different daylight simulation programs, can give different results. This may be due to restrictions in the program itself and/or to the skills of those setting up the models. It is therefore important for results to be acceptable and for users to know the limitations of the tools used (Iversen et al., 2013).