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An empirical validation of lighting energy consumption using the integrated simulation method

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ABSTRACT

The objective of this study is to evaluate the predictive accuracy of lighting energy consumption carried out by the EnergyPlus program and by the integrated simulation method (ISM), using the Daysim program. EnergyPlus calculates the interior illuminance based on the split-flux and radiosity method, and overestimates the interior illuminance, and we can see large differences in the EnergyPlus interior illuminance results. MBE by the split-flux method was found to range between 81.5% and 463.4%, and the largest MBE occurred at the deepest point. The Daysim program calculates the interior illuminance based on the ray-tracing method, and the largest MBE is −18.9%, at the middle point of the room. Lighting energy consumption differences are caused by the interior illuminance calculation algorithms in the simulation programs. As a result, the lighting energy consumption derived by the EnergyPlus program without ISM is approximately 34.6% smaller, than that of real consumption. The ISM was improved in the prediction accuracy of lighting energy consumption by 24.6% in absolute value. The results of the lighting energy consumption with ISM are relatively more accurate than the EnergyPlus results without ISM, because the modified lighting schedule is similar to the actual situation.

1. Introduction

The use of daylighting is a cost-effective way to reduce building energy consumption, and improve the quality of the visual environment. In an office building, lighting energy consumption comprises about 30% of the total energy consumption in South Korea. Therefore, we should consider the daylighting design, and apply lighting control systems to reduce energy consumption. In the design phase of the building, we can predict the building performance using computer simulation. There are various tools that have daylight algorithms, such as Radiance/Daysim [1,2], SPOT [3], ECOTECT [4], and EnergyPlus [5]. We therefore need to choose the appropriate daylight algorithm for each case.

The EnergyPlus program is an energy analysis and thermal load simulation program developed by the U.S. Department of Energy [5], while Daysim is a Radiance-based daylighting analysis tool that has been developed at the National Research Council Canada, and the Fraunhofer Institute for Solar Energy Systems in Germany [2]. The two programs give different results of lighting energy consumption, due to the differences of each daylight algorithm. According to a review [6], simulated daylighting results of the EnergyPlus and Daysim programs have divergences.

It is necessary to study the divergence between the simulation results, and the measurement of lighting energy consumption, with the application of a photosensor dimming control system. There are few articles about lighting energy consumption measurement, especially in terms of comparison between measurement and simulation results under real weather conditions in Korea. Therefore, from this study, we need to evaluate the prediction accuracy of lighting energy consumption. Also, it is important to evaluate the prediction of the interior illuminances in daylighting simulation, because they are closely related to the lighting energy consumption.

The main objective of this study is to evaluate the prediction accuracy of lighting energy consumption carried out by the EnergyPlus program, and the integrated simulation method (ISM), through comparison of the simulation results with measured data for Seoul in South Korea.

The following methods were used to evaluate the predictive accuracy of lighting energy consumption.

(1) Shadow ring correction of irradiance/illuminance meters for the measurement of diffuse components.
(2) Scale model illuminances comparison between measurement and daylighting calculation models (split-flux method and radiosity method) in EnergyPlus.

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(3) Comparison of measurement and simulation results of exterior irradiances and illuminances.
(4) Comparison of measurement and simulation results of interior illuminances with mock-up room.
(5) Evaluation of lighting energy consumption by EnergyPlus.
(6) Application of the integrated simulation method (ISM).
(7) Evaluation of predictive accuracy in the lighting energy consumption.

2. Simulation programs

2.1. EnergyPlus

The EnergyPlus program is based on a combination of BLAST [7,8] and DOE-2 [9]. This program calculates with the heat balance of BLAST. The EnergyPlus daylighting algorithm is derived from the daylighting calculation in DOE-2.1E [10], which is described in Winkelmann [11], and Winkelmann and Selkowitz [12]. The daylighting algorithms of EnergyPlus are based on the radiosity and split-flux methods. The program has two sections of daylighting simulation, namely Daylighting: Controls, which calculate the daylighting incidence through the split-flux method, and DElight, which determines the daylighting, based on the radiosity method [6]. The split-flux method calculates the daylight factor (DF) at a point, through the sum of the direct and reflected daylighting components [10]. The radiosity method calculates the radiation transfer among surfaces, based on the form factor, and it simulates the light performance in its radiant form. The split-flux and radiosity methods require a shorter calculation time; however, they have limitations in complex geometries. In this study, we use two daylighting calculation models of the Daylighting: Controls section, based on the split-flux method, and of Daylighting: DElights section, based on the radiosity method, to evaluate the daylighting performance in the EnergyPlus program.

2.2. Daysim

The Daysim program is a computer-based dynamic daylight simulation program developed by the National Research Council Canada (NRCC), which aims to predict the amount of daylight available in a building during the course of the entire year, under changing sky conditions [2]. This program calculates the daylight coefficient based on the Radiance program, and the sky model developed by Perez et al. [13]. Users first import the 3-dimensional model and climate data of the building site into the program. Daysim directly imports EnergyPlus Weather (EPW) files, containing a series of hourly direct and diffuse irradiances. Using the Perez sky model, direct and diffuse irradiances are converted into illuminances, for all sky conditions of the year. Daysim uses the ray-tracing method in the calculation of daylight illuminance. Ray-tracing simulates the performance of the light rays in the space, and calculates the lighting distribution at a certain point. An advantage of ray-tracing is that more accurate results can be derived, even from complex geometries.

2.3. The integrated simulation method (ISM)

There are many algorithms of daylighting calculation in energy simulation tools. The EnergyPlus program adopts simple daylighting calculation methods, such as the split-flux and radiosity methods, but in some cases these methods have limitations in predictive accuracy. In contrast, Daysim daylighting algorithms are based on the ray-tracing method, which is more accurate than those of EnergyPlus. Daysim daylighting results using the ISM (integrated simulation method) can be integrated into EnergyPlus [6]. Daylighting results derived from the Daysim program are daylight illuminance, and electric lighting schedule by target illuminance. We can get the electric lighting energy consumption, by importing the Daysim lighting schedule (intgain.csv file) into the EnergyPlus lighting schedule. This ISM can predict the electric lighting energy consumption more accurately in the EnergyPlus program, and this affects the building total energy consumption calculation.

Table 1
Window transmittance and surface reflectance of the mock-up room.

Field	Reflectance	Field	Transmittance
Floor	16%	Outer window of double skin facade	71%
Wall	50%	Inner window of double skin facade	78%
Ceiling	70%		

3. Methodology

3.1. Measurement and simulation layout

A mock-up room was defined that represents a cell type office (double-skin facade, 30° East) of 19.4 m^2 (3.5 m × 5.54 m), with a floor to ceiling height of 2.32 m, in the Korea University Daylighting Laboratory. For the daylighting evaluation (simulation and measurement), five illuminance sensors were placed 1 m from the window, with intervals of 1 m to the inside. In this model, the outer window of a double-skin facade has a window to wall ratio (WWR) of 100%, and the inner window has a WWR of 71%. The window transmittance and the reflectance of the inner surfaces are indicated in Table 1.

The outer window of the double-skin facade is a double Low-E window (outer Low-E glass), and has a visible transmittance of 7% lower than the inner window of double clear (see Table 1).

As shown in Fig. 1, the first class pyranometers (LP-PYRA 12, 02) measure the global horizontal irradiance and the diffuse horizontal irradiance (W/m^2), and the data logger (DataScan 3000) transfers the stored data to the lab computer. The illuminance meters (LP-PHOT 02) measure the global horizontal illuminance and the diffuse horizontal illuminance (lux) on the 6th floor (roof level). We use the Minolta T-10 illuminance meter for the measurement of interior illuminances. Data-management software, namely T-A30, was used to capture the measured results once per 10 min, averaged over 1 h. All the data, measured in seconds, were gathered on the computer. Measured data items are as follows:

(1) Exterior global horizontal irradiance (W/m^2).
(2) Exterior diffuse horizontal irradiance (W/m^2).
(3) Exterior global horizontal illuminance (lux).
(4) Exterior diffuse horizontal illuminance (lux).
(5) Interior work plane illuminance, 5 points (lux).
(6) Lighting energy consumption (Wh).

As shown in Table 2, measurement and simulations were performed for Seoul, South Korea (37.6°N, 126.7°E) during 2011/06/04–2011/10/20 (98 days). As mentioned above, the measured data (1–5) and the data from the Korea Meteorological Administration, such as the outdoor temperature (°C, hourly), total sky cover (hourly), and dew point temperature (°C, hourly), together with the calculated extraterrestrial horizontal irradiance (W/m^2, hourly) [14] were entered to write the new weather file of Seoul (of file type EPW).

Table 2
Measurement and simulation scheme of the mock-up room.

Location (latitude, longitude)	Simulation period
Seoul, South Korea (37.6°N, 126.7°E)	2011/06/04–2011/10/20 (98 days)