Comparison of Climate-Based Daylighting in Two Integrated Simulation Tools: DIVA and OpenStudio

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ABSTRACT: Integrated daylighting and energy simulation tools aim to accomplish a thorough and accurate whole-building energy analysis in buildings and resolve the problems associated with discrete processes. OpenStudio and DIVA are two simulation tools that provide integrated daylighting and energy simulation. The objective of this study is to compare OpenStudio and DIVA software in daylighting performance simulation with results from physical experiment. Through this study Useful Daylight Illuminance (UDI) as an indication of useful annual climate-base daylight was calculated for a toplighting model in DIVA, OpenStudio and experiment. Identical Radiance parameters have been used for both simulations. The results show that the daylight quantities predicted by DIVA are closer to the measured experimental data collected from monitoring the physical model on a year-round basis.

Keywords: DIVA, OpenStudio, Radiance parameter, Useful Daylight Illuminance (UDI)

INTRODUCTION

Integrated daylighting and energy simulation tools aim to accomplish a thorough and accurate whole-building energy analysis in buildings and resolve the problems associated with discrete processes. OpenStudio and DIVA are two simulation tools that provide integrated daylighting and energy simulation. The focus of this paper is to compare climate-based daylighting simulation in DIVA 2.0 and OpenStudio v. 0.11.0, which are the latest versions of the tools to the date, with annual measured data from physical experimentation.

Both DIVA and OpenStudio use Radiance as lighting simulation engine and incorporate Daylight Coefficient (DC) method for annual daylighting calculation. The purpose of this paper is to compare daylighting performance in a toplighting model based on calculated results from DIVA, OpenStudio and experiment. In order to make simulations comparable to each other, the same set of Radiance parameters were selected in both tools. Climate-based daylighting metric, UDI (Useful Daylight Illuminance), is used as a performance metric for comparing the simulation tools with the physical experiment.

BACKGROUND

Two approaches exist for the incorporation of high quality lighting simulation methods with whole-building simulation tools:

- A discrete process, whereby two stand-alone simulation tools are used separately.
- An integrated process, where a single program incorporates two separate simulation engines for lighting and whole-building energy simulations.

Studies have been conducted by using a discrete process to incorporate high quality lighting simulation with whole-building simulation tools [1]. These studies showed that electric energy savings due to daylighting in buildings were calculated more accurately when Daysim (with Daylight Coefficient method for annual daylighting simulation) replaced the built-in daylighting simulation method in DOE-2.2. The reason lies in the fact that the Daylight Coefficient (DC) method uses Radiance backward raytracing algorithm [2] rather than the built-in split-flux and radiosity algorithms generic to whole-building simulation tools such as DOE-2.2 [3].

Integrated tools, such as DIVA-for-Rhino [4] and OpenStudio [5] have been developed to solve the problems associated with the discrete processes of daylighting and energy modelling. Currently, the integrated tools reside in a developmental stage and their shortcomings in modelling, simulation and application are being resolved at each updated version of the software.

The fundamental benefits of the integrated process over the discrete process include reduced errors and less execution time during the simulation process. Modelling plays a key role in conducting an accurate simulation. In discrete processes, using two separate simulation tools increases the risk of errors due to discrepancies between a daylighting model and an energy model. In addition to geometry of the model, other shared information between lighting and energy simulations such as electric lighting controls and schedules of operation would be inserted once in an integrated process; therefore, the errors caused by the dissimilarities between inputs in two separate simulation tools can be reduced. Furthermore, transferring data from one simulation program to the other would require more time for data management in the discrete processes than that in the integrated methods [6].

Both DIVA 2.0 and OpenStudio v. 0.11.0 use RADIANCE for single-time daylight calculations; they employ Daylight Coefficient (DC) Method for annual daylighting simulation, and they use EnergyPlus for whole-building energy simulation [4, 5].

This study focuses on the comparison between DIVA and OpenStudio in terms of annual climate-based daylighting. Although DIVA and OpenStudio employ the same source engine, Radiance, and use the same method for annual daylighting simulation, DC method, their results might be different when a single model is simulated in the two programs. The comparison of annual daylighting performance of DIVA and OpenStudio has never been performed before. This study aims to fill this gap by comparing the outcomes of the simulation tools with measured data from monitoring a physical model.

Comparison of other lighting simulation tools has been previously investigated. Ochola et al. [7] provide a comprehensive literature review of lighting simulation tools, their comparison and validation. In this extensive literature review, validation and comparison of lighting simulation tools are categorized into two large groups:

- Comparisons based on replicating a built realist such as studies by Roy [8], Ashmore and Richens [9], and Galasiu and Atif [10]
- Comparisons under controlled laboratory settings such as studies by Mardaljevic [11], Reinhart and Walkenhorst [12], Reinhart and Brenton [13]

In literature review, lighting simulation tools showed higher accuracy levels under controlled condition of laboratory. In lighting simulation field, no general consensus is yet achieved for defining the “acceptable” degree for accuracy in simulations. CIE [14] reported that the acceptable range of difference between measurement and simulation would be 10% for average illuminances and 20% for point values.

SIMULATION TOOLS

DIVA 2.0 is a plug-in to Rhino that exports scene geometries, material properties, and sensor grids into the format required to enable the use of Radiance and EnergyPlus [4, 14]. To convert a Rhino file to a valid Radiance mode, DIVA employs Python, which is an open source scripting language that is compatible with Rhino and translates Rhino geometry to Radiance scripts.

Openstudio is the U.S. Department of Energy’s middleware software development kit. It creates a plug-in to SketchUp that develops series of scripts to support Radiance and EnergyPlus simulations [5,15]. OpenStudio uses Ruby, an open source scripting language that is compatible with SketchUp, to convert a model to a valid Radiance and EnergyPlus mode.

BUILDING PARAMETERS

Multiple physical models outfitted with top-lighting and side-lighting systems were built and installed on top of the North Carolina State University Daylighting Lab, located in Raleigh, USA (Figure 1).

Figure 1: Physical models monitored on a year-round basis

Among these models, a toplighting model was selected and simulated in DIVA and OpenStudio for comparison and analysis (Figure 2).

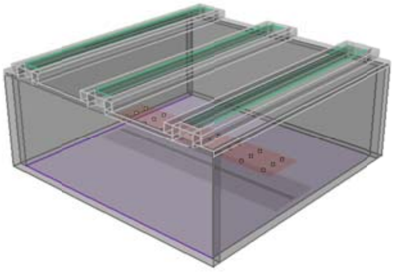

Figure 2:Toplighting model

The model represents an office space with 8.68 m x 8.68 m (28.5’ x 28.5’) interior dimensions in floor plan and 3.35 m (11’) ceiling height. This building has three linear skylights installed on top of the roof with 0.76 m x 8.68 m (2.5’ x 28.5’) dimensions located parallel to the east-west axis. The height of the light-wells of skylights is 0.3 m (1’).

The scale model was created at 1:24 (½” = 1’-0) scale. A row of eight photometers (illuminance meters) is located on the north-south axis of the floor (Figure 3).

The glazing material used in the skylights was clear glass with 60% visible light transmittance. Light reflectances of the interior surfaces were: 62% for walls, 30% for floor, and 90% for ceiling. The physical model was located on a large ground surface with 30% light reflectance. No obstructing elements were located in proximity of the physical model.

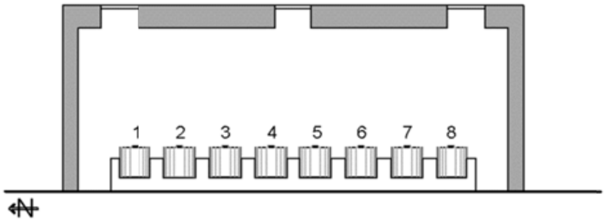

Figure 3: Toplighting model section

SIMULATION

The daylighting models were built in Rhinoceros and SketchUp, which are the modelling environments for DIVA and OpenStudio tools respectively. Building dimensions, materials, and location of sensors were exactly replicated in the simulated models.

For simulation in DIVA, Rhino program allows creating both interior and exterior layers of the building envelope in the modelling process. On the contrary, SketchUp program only allows creating a single plane surface for modelling the building. Therefore, only interior surfaces of the model were drawn in SketchUp; thickness of walls and light-wells were generated as “exterior shading” elements.

The daylight model is clearly separated from thermal model in DIVA. Two models in two distinct layers should be drawn and two sets of materials are defined to introduce the lighting and thermal properties of the materials. However, in Openstudio, a single model, in .osm format, is shared by both daylight and thermal simulations and contains geometrical and material properties of the building.

Materials are defined in two distinct methods in DIVA and OpenStudio. In DIVA, lighting properties of material are defined separately from their thermal properties. DIVA provides a list of typical construction materials in a text file called material.rad, which is located in C:\DIVA\Daylight when the software is installed. For creating a customized material, lighting properties of materials should be scripted in the same fashion as materials are created in Radiance. For example, a clear glazing with 60% visible light transmittance is scripted as the following in material.rad in DIVA:

```
void glass Clear_60Vt
0
0
3  0.68  0.68  0.68
```

The Radiance format for glazing materials is composed of three components, which are visible light transmissivity of RGB (Red, Green and Blue) colours through the glazing material.

On the other hand, OpenStudio defines lighting properties of materials along with their thermal properties. In SketchUp, when the .osm file is being created, materials are defined in the same fashion as in EnergyPlus. To define surface reflectances, visible light absorptance of the innermost layer of material is defined for each surface. To create a customized glazing material, a new “simple glazing material” is created and three parameters are identified: U-value, SHGC, and Visible Light Transmittance (of 60% for the toplit model) through the glazing material.

In the simulation processes, annual hourly illuminances were recorded across the task surface in the toplighting model. Radiance parameters were increased from the default values and set at the same level for each simulation tool. Table 1 shows the Radiance parameters involved in the simulations.

RADIANCE PARAMETERS

The following parameters are involved in the simulations:

- Direct Threshold (dt) is a fraction which indicates when shadow testing stops.
- Direct Certainty (dc) ensures the absolute accuracy of direct calculation is equal or higher than a fraction of -dt parameter.
- Direct Jitter (dt) is a fraction that gives a smoother but less accurate rendering.
- Direct Pretest (dp) defines the number of samples per steradian in a pretest.
- Ambient Bounces (ab) define maximum number of inter-reflections between surfaces that the program calculates.

- Ambient Divisions (ad) defines the number of samples sent out from each sample hemisphere.
- Amibient Supersamples (as) is set at a quarter of –ad.
- Limit Weight (lw) indicates the weight or contribution of each ray in a render as a fraction.
- Ambient Accuracy (aa) is the maximum error permitted in the indirect irradiance interpolation.
- Ambient Resolution (ar) indicates the resolution of simulation and relates to –aa and maximum scene dimension.

Radiance parameters used for this study are illustrated in Table 1 with minimum and maximum available values for each parameter.

Table 1: Radiance parameters

RADAINCE PARAMETERS		Min	Max	OpenStudio & DIVA
DIRECT THRESHOLD	dt	1	0	0.05
DIRECT CERTAINTY	dc	0	1	0.75
DIRECT JITTER	dj	0	1	0
DIRECT PRETEST	dp	32	-	2048
AMBIENT BOUNCES	ab	0	7	7
AMBIENT DIVISIONS	ad	0	4096	2500
AMIBIENT SUPERSAMPLES	as	0	1024	625
LIMIT WEIGHT	lw	0.05	0	0.0005
AMBIENT ACCURACY	aa	0.5	0	0.1
AMBIENT RESOLUTION	ar	8	-	DIVA: 300 OSM: 256

DATA ANALYSIS

For comparing the annual climate-based daylight data from experiment and simulations (DIVA and OpenStudio) "Useful Daylight Illuminance" or UDI was calculated for the toplighting model located in Raleigh, USA.#UDI is defined as the annual rate of illuminances across the work plane where all the illuminances are within the range 100-2000 lux [16]. This calculation is based on occupied hours in space, which for this study was from 8am to 5pm all days. The total occupied hours in a year were 3650 hours (365 days multiplied by 10 occupied hours a day).

UDI summarizes the voluminous time-series illuminance data to a single percentage for each point (sensor) in space, which represents the ratio of comfortable lighting condition in occupied hours [8]. UDI is also related to the annual required lighting energy for the space. Figure 4 illustrates the calculated UDI based on the experiment and simulation results for the model.

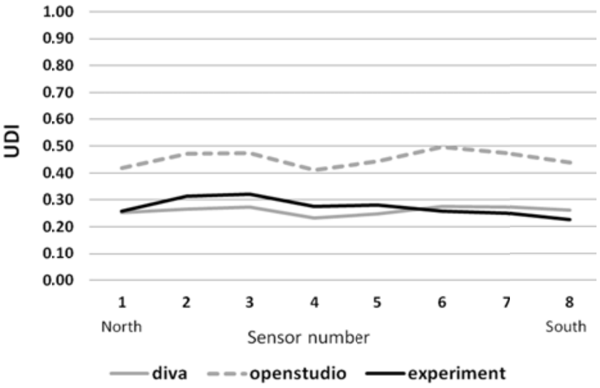

Figure 4: UDI, useful illuminance between 100 and 2000 lux

As mentioned in building parameters section, the slotted skylights extended in east-west direction and the sensors measured illuminance on the middle north-south axis of the model at task surface. Receiving light from horizontal apertures creates relatively similar daylighting condition at all sensors' locations and a fairly flat curve in the UDI results.

As shown in Figure 4, calculated UDI from experiment and simulation for toplighting model has different values at each sensor; however, they fallow a general trend. UDI results from DIVA and experiment are comparable, depicting a range of 22%-32% useful daylight illuminance at all sensors. Nevertheless, OpenStudio shows roughly 18% higher useful daylight illuminance at all sensors' locations.

Figure 5 shows the percentage of the annual occupied hours in which daylight illuminance reaches higher than 2000 lux at each sensor. Based on the experiment, during 68%-78% of the occupied hours, daylight illuminance exceeds 2000 lux at all sensors. Again, results from DIVA are closer to the experimental results. OpenStudio, however, shows lower number of hours with extreme daylighting condition (illuminance> 2000 lux).

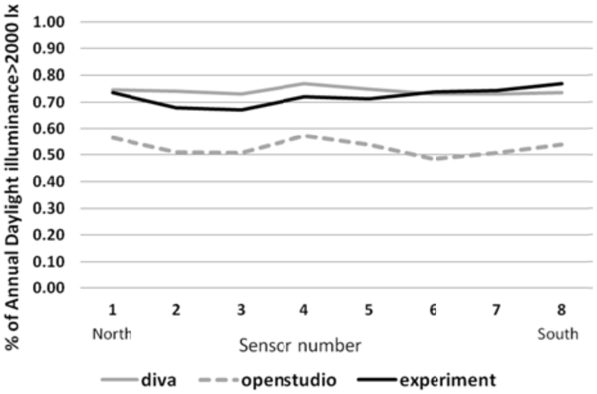

Figure 5: Percentage of annual illuminance higher than 2000 lux

In Figure 6, lower range of annual daylight illuminance is depicted with two simulation methods and the experiment. In Figure 6, annual occupied hours in which daylight illuminance falls below 100 lux are calculated and divided by the total 3650 occupied hours. Experimental results show that low daylight illuminances (lower than 100 lux) occurred rarely in the toplit model due to the fact that the model has horizontal apertures facing the luminous sky for most occupied hours. As Figure 6 illustrates, results from DIVA are closer to experimental results, but OpenStudio generates slightly higher results.

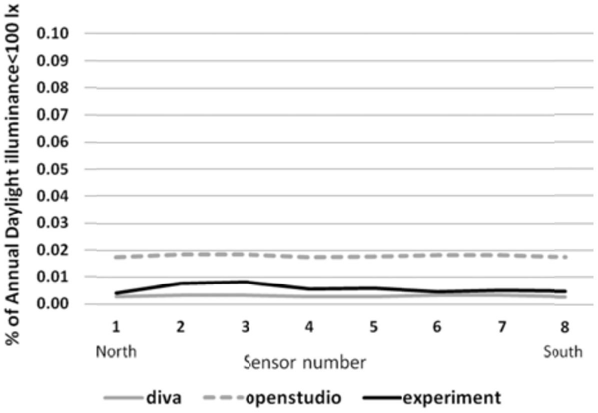

Figure 6: Percentage of annual illuminance less than 100 lux

CONCLUSION

Both DIVA and OpenStudio use Radiance as the lighting simulation engine and incorporate Daylight Coefficient (DC) method for annual daylighting calculation. Although the same set of Radiance parameters were selected for the two simulation tools, the predicted daylight quantities were different. It appears that DIVA produces more accurate results when using measured experimental data as the benchmark. Analyses of annual illuminance data show that OpenStudio does not accurately estimate daylighting extreme conditions when the sensors receive illuminances higher than 2000 lx in toplighting cases. As a result, useful daylight illuminance (UDI) was higher in OpenStudio than the real condition and the DIVA simulation.

The substantial difference between the two simulation tools can be caused by Radiance parameters that are not settable through the graphic user interface in each simulation tool. Each simulation tool allows a limited number of Radiance parameters to be changed by users and the rest of the parameters are set at the Radiance default values. For instance, ambient resolution could be changed in DIVA during an annual daylighting simulation but in OpenStudio, -ar is set automatically at 256, which is the default value in Radiance. However, the 300 –ar selected for DIVA simulation is close enough to the 256 –ar default value used in OpenStudio. Daylighting simulation and comparison between simulation tools will be more convenient if -aa and -ar are added to the OpenStudio application options for setting Radiance parameters.

Although crucial Radiance parameters in daylighting simulation have been covered in this paper, further research should be conducted on the Radiance parameters that are not settable in the two simulation tools in order to find out the reason for discrepancy between OpenStudio and DIVA.

The other contributing factor to the discrepancies between DIVA and OpenStudio could be the way materials are simulated in each tool. As mentioned in the simulation process, DIVA identifies lighting properties of materials as the way materials are scripted in Radiance. OpenStudio, however, identifies lighting properties of materials through EnegyPlus material scripts. Future research will focus on the method by which each simulation tool reads the materials scripts and investigating if this item contributes to differences in the results.

In OpenStudio, daylighting properties are modified in SketchUp environment and daylighting simulation is run in OpenStudio application. In the current version of the OpenStudio application, changing items such as number and location of sensors, illumination set-point, lighting control systems and material properties are not provided. For modifying each of these parameters, users need to move back to the SketchUp environment. This limitation could be solved if OpenStudio developers provide more daylighting options in the next versions of the OpenStudio application.

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