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ScienceDirect
ELSEVIER
Energy 32 (2007) 1855–1870
ENERGY
www.elsevier.com/locate/energy

An empirical validation of the daylighting algorithms and associated interactions in building energy simulation programs using various shading devices and windows

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Received 8 September 2006

Abstract

Empirical validation of building energy simulation programs is an important technique in examining the effectiveness and accuracies of implemented algorithms. In recent years, daylighting algorithms incorporated in building energy simulation programs have become increasingly sophisticated in their abilities to predict the illuminance, light power reductions, and the associated thermal load interactions. The focus of this study was to examine measured and simulated light levels in an actual building constructed for research purposes. Daylighting models were constructed in EnergyPlus and DOE-2.1E and the predicted illuminance and light power were compared with measurements; an assessment of heating and cooling interactions using a variable-air-volume reheat (VAVRH) system was also performed by analyzing reheat coil powers for the VAV boxes. The average differences from EnergyPlus for reference point daylight illuminance, light power, and reheat coil power predictions were within 119.2%, 16.9%, and 17.3%, respectively. DOE-2.1E predicted reference point daylight illuminances were within 114.1%, light powers were within 26.3%, and reheat coil power were within 25.4%.

Keywords: Daylighting; Empirical validation; Building energy simulation tools

1. Introduction

During the last 30 years, engineers and architects have increasingly relied on building energy simulation programs to design and retrofit buildings. Increased computer capacity has allowed for the implementation of complex control algorithms used in modern structures to be simulated by various programs. One such control strategy is daylighting control. Daylighting controls take advantage of daylight entering the space through windows, skylights and/or light wells and adjust the amount of artificial light to the space to control the light level at a given point. Typically, a controller mounted in the ceiling measures the illuminance on a reference plane. When the illuminance on this reference plane deviates from a specified set point, the controller sends feedback to dimmable ballasts which cause the lights to dim or illuminate to maintain prescribed light levels. Building energy simulation programs combine room geometry and surface optical properties, window information, and window shading (if installed) into the algorithms to compute illuminance(s) at a reference point(s) in the zones. This information, along with detailed lighting and ballast specifications, is used to calculate the amount of light dimming required to maintain a fixed illuminance.

Important and necessary components for evaluating these types of programs are rigorous validations. Judkoff [1] identifies three types of validations for building energy simulation programs: analytical validations, program-to-program comparisons, and empirical validations. In analytical validations, the building energy simulation programs are configured according to a case where the

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0360-5442/$ - see front matter
doi:10.1016/j.energy.2007.02.005

Nomenclature

D_i	difference between experiment and predicted values for a given value
$\overline{D}$	mean difference for a given array
$\lvert\overline{D}\rvert$	mean absolute difference for a given array
D_{max}	maximum difference between experimental and predicted values for a given array
D_{min}	minimum difference between experimental and predicted values for a given array
D_{rms}	root mean squared difference between experimental and predicted values for a given array
$D_{95\%}$	95th percentile of the differences between experimental and predicted values for a given array
N	number of points in the array that were used for the analysis
$OU_{Experiment}$	95% credible limits or overall uncertainty from experiment
$OU_{EnergyPlus}$	95% credible limits or overall uncertainty from MCA
$\overline{OU}$	average overall uncertainty calculated for 95% credible limits
UR_i	uncertainty ratio for a given hour, no units
$\overline{UR}$	average uncertainty ratio for a given array, no unit
UR_{max}	maximum uncertainty ratio for a given array, no units
UR_{min}	minimum uncertainty ratio for a given array, no units
$\bar{x}$	arithmetic mean for a given array
x_{min}	minimum quantity for a given array
x_{max}	maximum quantity for a given array

analytical solution is known. Program outputs are then compared with the analytical solution. The advantages for this type of validation include: no input uncertainties, an absolute truth standard, and low costs; the primary disadvantage is that analytical solutions are limited to very simple cases. In program-to-program comparisons, the same input specifications are used and the outputs from each program are then compared. The advantages include: relatively inexpensive and straightforward and the validations can be as complex as necessary. The disadvantage is that there is no truth standard; so it is impossible to ascertain which program (s), if any, is (are) correct. For empirical validations, an actual experiment is run and then modeled in building energy simulation programs. The advantages are that there is an absolute truth standard within experimental uncertainty limits, and it can be as complex as required. The primary disadvantage is that empirical validations are expensive to perform.

Numerous daylighting algorithms have been developed and validated that explore different types of shading devices and illuminance predictions [2–6]. The International Energy Agency's Task 21 [7] was assembled to investigating daylighting for design tools and software in buildings. One of the most popular daylighting algorithms used in the design of buildings [8] was installed in DOE-2.1E and is analyzed in this paper.

Different facets of the DOE-2.1E daylighting algorithm has been already explored in earlier studies, including numerous empirical validations [9–13] and several studies that use the program as a tool for optimizing the daylighting performance of buildings [14–17]. Other empirical validations that did not emphasize daylighting have been performed in the PASSYS project [18–20], IEA Annex 21/Task 8 [21], and IEA Task 34/Annex 43 [22–25] that explore different facets of the building envelope and the associated solar gains with and without solar shading devices.

The focus of this research is to evaluate the daylighting algorithms and connected load interactions in EnergyPlus [26] and DOE-2.1E [27]. The experiment was performed in test rooms in a research facility in conjunction with the International Energy Agency's Task 34/Annex 43 Subtask C. For this study, various shading devices (internal and external) and windows were installed in different combinations to assess the performances of each building energy simulation program. Various statistical parameters were employed to compare the results. Experimental uncertainties were computed and a Monte Carlo analysis (MCA) was used to quantify how uncertainties in program input parameters (thermophysical properties and instrumentation uncertainties) propagated through a building energy simulation program (in this case EnergyPlus) and impacted output predictions.

2. Facility layout

The building where the research was performed is uniquely equipped for empirical validations and meets all nine criteria for a high quality validation data set [19]. The facility is located on the campus of a community college in Ankeny, Iowa USA. The structure is comprised of eight test rooms, a computer room, offices, two classrooms and other rooms necessary for the support and operation of the facility. A drawing of the building is shown in Fig. 1. The test rooms were constructed in symmetrical pairs to provide side-by-side testing with exposures to nearly identical outside thermal loads. The volume and floor area of the test rooms are 61.23 m^3 and 23.63 m^2, respectively. Three pairs of test rooms are located at the perimeter of the building (east, south, and west) and the other two test rooms are situated inside the facility. There are three air-handling units (AHUs) in the facility. Test rooms denoted as A and B are served by different two nearly identical AHUs; the other AHU serves the rest of the facility. The