DELIGHT2 DAYLIGHTING ANALYSIS IN ENERGY PLUS:
INTEGRATION AND PRELIMINARY USER RESULTS

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ABSTRACT
DElight is a simulation engine for daylight and electric lighting system analysis in buildings. DElight calculates interior illuminance levels from daylight, and the subsequent contribution required from electric lighting to meet a desired interior illuminance. DElight has been specifically designed to integrate with building thermal simulation tools. This paper updates the DElight capability set, the status of integration into the simulation tool EnergyPlus, and describes a sample analysis of a simple model from the user perspective.

INTRODUCTION
In a previous paper (Hitchcock, et al., 2003) we described the then current and planned capabilities and analysis methods for DElight2, a simulation engine for daylight and electric lighting system analysis in buildings. Major DElight2 enhancements included full radiosity interreflection calculations and analysis of complex fenestration systems (CFSs). DElight was specifically designed to integrate with whole-building thermal simulation tools on a time-step basis.

Since then, DElight2 implementation and full integration with the energy analysis tool EnergyPlus v1.2.1 (Crawley, et al., 2001) have been completed and the combined tool is undergoing validation and preliminary use. This paper presents:
(1) A brief update on DElight capabilities.
(2) A discussion on the use of Bidirectional Transmission Distribution Functions (BTDFs), both internally generated and from external sources (e.g., IEA-SHC Task 21, 2000), as Complex Fenestration Systems (CFS) characterizations in DElight analyses. BTDFs are now becoming more widely available from measurement and simulation activities (IEA-SHC Task 31). This is an important new analysis capability in DElight2. Validation results for DElight analysis of CFS systems based on BTDFs will also be presented and discussed.
(3) A discussion of results for a simple test case that highlights the DElight-EnergyPlus integration features. This example has two aperture variations, a simple window and the same aperture with a light redirecting CFS type. These variations show quantitatively the impact of the daylighting system, including interior illuminance, and the hourly effect on lighting electricity use for a lighting system model.

DELIGHT2 CURRENT CAPABILITIES
DElight2 capabilities added since our previous paper include:
• Building Geometry Library extensions, including (1) arbitrary polygon surfaces, subsurfaces, gridding, and coplanarity testing for 3D polygon vertex data sets, and (2) partial surface-to-surface visibility testing (a full implementation will be completed soon).
• External data file inputs and pre-processing for use in DElight analyses include IESNA (IESNA, 1987) and RAD (Larson, 1998) file formats for lighting fixture data, and sky data. Although DElight does not currently use this data format for analyzing lighting fixtures, this could be implemented in the future. This data format was used as part of the validation study described below for importing sky luminance data.
• Full implementation of BTDF-based CFS analysis, discussed in detail below.
• Full integration with EnergyPlus, discussed in detail and including an example below.

COMPLEX FENESTRATION SYSTEMS
The ability to analyze CFSs characterized by BTDF datasets both internally generated and input from external data files in IEA Task 21 format has been fully implemented.

In addition to analyzing simple fenestration systems, DElight includes the capability of analyzing complex fenestration systems such as geometrically complicated static shading systems (e.g., roof monitors) and/or optically complicated glazings (e.g., prismatic or holographic glass). This capability is
based on characterizing these CFSs using bi-
directional transmittance distribution functions
(BTDF). In general, BTDF data for a specific CFS
must be either measured or simulated (e.g., using ray-
tracing techniques) prior to employing DElight to
analyze it within EnergyPlus.

The current implementation of DElight CFS
calculations within EnergyPlus supports two
approaches to the input of BTDF, an analytical
approach and a file-based approach. Two analytical
CFS BTDF types are currently supported, WINDOW
and LIGHTSHELF (the actual analytical
implementation in DElight2 for the latter should
perhaps more correctly be called a light
REDIRECTING system). The file input capability
allows access to BTDF libraries being developed by
others. The file-based approach requires that a user
have access to a data file containing raw BTDF data
that DElight reads as additional input during its
analysis calculations. BTDF data files are described
separately since it is anticipated that individual
EnergyPlus users will not create these data files
themselves.

DELIGHT – ENERGYPLUS
INTEGRATION

The DElight – EnergyPlus integration effort has now
been completely implemented. This allows DElight
daylighting analyses to be used to support the
analysis of impacts of daylighting and lighting
control algorithms in EnergyPlus thermal and energy
use simulations. The integration at the interface level
allows DElight input to be completely specified in
EnergyPlus input language, and also provides
analysis output reporting, and runtime error handling
through EnergyPlus facilities.

We will illustrate the details of how an integrated
DElight2EnergyPlus analysis is specified and how
the results are reported for a simple example.

Example Analysis

The example is a simple model with two 4.5m square,
2.5m high, side-by-side zones with identically placed
window apertures in the center of their south walls.
Each zone has an electric lighting system whose
maximum power is reduced by the daylighting
incident on illuminance sensors at a 0.9m workplane
height located on a centerline perpendicular to the
window aperture. In Zone 1, the aperture is a simple
double-glazed window; in Zone 2 the aperture is an
analytical CFS that acts like an upward-redirecting
light system – all downward directed light from the
sky incident on this CFS is redirected upward at the
same angle from the horizontal into the space. This
upward-redirected light tends to illuminate the ceiling
and diffusely reflect light deeper into Zone 2 than the
window does in Zone 1.

Example Inputs

Figure 3 at the end of the paper shows the relevant
parts of the thermal and DElight-related inputs for
Zone 2 of this example. The ZONE, LIGHTS,
SURFACE: HeatTransfer, and SURFACE:
HeatTransfer:Sub objects are standard
building components for thermal analysis. The
remaining three objects (indicated in bold font)
specify the details of the DElight2 analysis.
Comments embedded in the input syntax with a “!”
character explain the various parameters in more
detail.

- DAYLIGHTING:DElight

The first input object required for invoking the
DElight method is the Daylighting:DElight object,
which defines the parameters of each daylighting
zone within a building. This object must be
associated with a specific thermal zone within the
building for which the reduction in electric lighting
due to daylight illuminance will be accounted.

- DAYLIGHTING:DElight:Reference
  Point

The second input object required for invoking the
DElight method is the Daylighting:DElight: Reference
Point object, which defines the parameters of each
Reference Point within the associated DElight
daylighting zone. This object must be associated with
a specific Daylighting:DElight object instance. There
may be up to a maximum of 100 Reference Points for
each DElight daylighting zone. Each Reference Point
that is input does NOT need to be included in the
control of the electric lighting system within the zone.
This is determined by the fraction of the zone
controlled by each Reference Point (which can be
input as 0).

- DAYLIGHTING:DElight:Complex
  Fenestration

The third input object related to the DElight method is the
Daylighting:DElight: Complex Fenestration object.
The DElight daylighting analysis method can be
applied to daylighting zones that contain only simple
fenestration systems such as windows and skylights
that are standard EnergyPlus sub-surfaces. In this
situation, no Daylighting:DElight: Complex
Fenestration object would be input. The example
Zone 2 analytical CFS BTDF type is the LIGHTSHELF
(more correctly, a light REDIRECTING system). DElight
only deals with the visible spectrum of light
transmitted through a Complex Fenestration. To
account for the solar/thermal influences of a Complex Fenestration, a geometrically coincident subsurface that will be accounted for by methods already within EnergyPlus must be defined in the input data file and referenced here. This must be a valid name that has been associated with a Surface:HeatTransfer:Sub WINDOW contained in the same EnergyPlus input data file, as shown earlier in the example input. The geometry for the Complex Fenestration is taken from the geometry input for this standard EnergyPlus subsurface, hence the term “Doppelganger.” This is an interim solution to the issue of accounting for solar/thermal influences that will likely change as techniques analogous to the daylighting analysis of BTDF are developed.

Example Outputs

The Report Variable specification shown in Fig. 3 produces a standard EnergyPlus report, LTG Power Multiplier from Daylighting. This is the amount by which the overhead electric lighting power in a zone is multiplied due to usage of DElight calculated daylighting to dim or switch electric lights. For example, if the multiplier is M and the electric power without dimming is P, then the electric power with dimming is M*P. The multiplier varies from 0.0, which corresponds to maximum dimming (zero electric lighting), to 1.0, which corresponds to no dimming. This output report is produced in a comma-separated-value format that can be directly imported into a spreadsheet and plotted. Figure 1 below shows the plotted lighting power multipliers for one week in January for the example.

![Figure 1. Lighting power multipliers for ZONE1 with window and ZONE2 with upward-redirecting CFS.](image)

For the seven-day simulation period shown, three of the days were cloudy and four were sunny. On cloudy days, the lighting power reductions were no more than about 10% for the window and 20% for the CFS. On sunny days, the reductions were 50% to 70% for the window and fully 100% for the CFS. These results clearly show the ability of the CFS to redirect light much farther into the space from the aperture, an expected result. An annual analysis could directly compare the difference in lighting electricity consumption and peak demand for a real climate, and the subsequent impact on thermal loads within the zone from this electric lighting.

This example shows quantitatively the impact of daylighting systems through the hourly effect on lighting electricity use when sensors that detect the amount of natural light and controls that correspondingly modulate lighting electricity are simulated.

VALIDATION

DElight2 recently participated in an IEA Solar Heating and Cooling Annex Task 31 Daylighting validation exercise specifically focused on the ability to simulate CFS performance, as characterized by measured BTDFs (Maamari, et al., 2005). The comparisons were based on measurements and corresponding simulations in a simple-geometry test box for combinations of CFS BTDFs and measured skies.

The DElight2 results for a particular combination of a CIE overcast sky and a measured BTDF representing Serraglaze (a light-redirecting glazing) are shown in Figure 2 below. The data values represent illuminances at defined sensor positions, spaced equidistantly along a floor-level symmetrical center line, from light incident through an aperture centered in the top of the square test box. The lines represent the simulation results; the data points with 10% error bars represent the measurements. The upper dataset represents an empty aperture; the lower dataset a CFS in the aperture. In this case, the RMS difference was on the order of a few percent. For all combinations of comparisons performed, the aggregate RMS differences were on the order of 10%. These early results are promising, and indicate that the simulated accuracies are good enough that DElight is suitable for doing quantitative estimates of performance of these systems for building design purposes.
CONCLUSIONS

This material shows that the integrated EnergyPlus-DElight tool is robust, usable, and capable of providing sufficiently accurate quantitative information about the performance of daylighting and lighting control systems in actual buildings, suitable for aperture selection and system design.

The methods related to characterizing and analyzing CFS using BTDF are still evolving. DElight is an early implementation of CFS analysis methods. These methods, and the input associated with them here, will likely change in the future.

ACKNOWLEDGMENT

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, Building Technologies Program, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

REFERENCES


Figure 3. EnergyPlus zone, lighting, surface, window, reporting, and daylighting objects for the example test case discussed in the text.