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DAYLIGHTING AND ENERGY SIMULATION WORKFLOW IN PERFORMANCE-BASED BUILDING SIMULATION TOOLS

Ladan Ghobad, Ph.D., Associate Member
Glumac, Sacramento, CA

ABSTRACT

Accurate daylighting analysis for buildings has been developed along with energy simulation in performance-based analysis tools, such as: DesignBuilder, DIVA, Honeybee, and Insight360. However, users in professional practice do not have a complete understanding of the capabilities and limitations of these tools. Although these programs use the same (or equivalent) simulation engines, they could generate different results due to having different simulation workflows, default inputs, and user-defined inputs through the Graphic User Interface (GUI).
This paper explains the workflow in each simulation tool and describes their capabilities and limitations for daylighting and energy simulation.

INTRODUCTION

This study focuses on simulation programs which can perform both daylighting and energy simulation. Four selected programs are DesignBuilder, DIVA for Rhino, Honeybee for Grasshopper, and Revit Insight360. Although other computer programs such as OpenStudio and IES are capable of both types of simulations, they will not be discussed here due to publication limitations. Those tools will be separately discussed in a paper in the future.
This paper explains daylighting and energy simulation workflows in the selected tools; it explains the input options, which are provided in Graphic User Interface (GUI) for each tool, and it describes the tools' capabilities in the following categories:

1. Geometry modelling
2. Construction materials
3. Daylighting simulation:
   - Single-point-in- time daylighting
   - Annual climate-based daylighting
4. Energy simulation:
   - HVAC systems options
   - HVAC zoning
   - Internal loads and building schedules
   - Lighting schedule and daylighting impact on energy

It should be highlighted that the main purpose of this paper is to introduce the workflow, explain the modeling process, and report the full spectrum of features and limitations that each program has. While this report could be used as a manual for step-by-step guidance for daylighting and energy simulations, it did not intend to compare the simulation results between the tools. That topic will be pursued in a separate paper in the future.

METHODOLOGY

All the information in this paper is provided by program developers on their websites, tutorials, and help/support forums, or is provided directly from the support team to the authors.
Daylighting and energy simulation workflow is examined through modelling an actual project using these four programs:

1. DesignBuilder
2. DIVA for Rhino
3. Honeybee for Grasshopper
4. Insight360 for Revit

OVERVIEW OF THE FOUR PROGRAMS

DesignBuilder
www.designbuilder.co.uk
DesignBuilder specializes in providing advanced energy modelling analysis to building designers. DesignBuilder, developed in 2005 in the UK, added daylighting capabilities using Radiance and a GUI for EnergyPlus HVAC systems in 2011 (DesignBuilder website). Annual climate-based daylighting with DAYSIM was provided in DesignBuilder V-5.2 Beta version in 2017.

DIVA for Rhino
diva4rhino.com
DIVA for Rhino was initially developed by the Graduate School of Design at Harvard University between 2009 and 2011 for daylighting analysis. DIVA is the pioneer in adding DAYSIM for climate-based daylighting with the use of Radiance engine (Jakubiec& Reinhart, 2011). Energyplus is incorporated to the program for single thermal zone energy modelling.

Honeybee for Grasshopper
www.grasshopper3d.com/group/ladybug
Ladybug and Honeybee were first developed in 2013. These tools are two open source plugins for Grasshopper, utilizing this visual programming tool for environmental analysis of buildings. While Ladybug

focuses on weather analysis, Honeybee introduces different simulation engines, including EnergyPlus, Radiance and DAYSIM into Grasshopper (Sadeghipour Roudsari M., Pak M., 2013).

Insight360 for Revit

insight360.autodesk.com/oneenergy

In 2015, Autodesk developed Insight360 for Revit with the purpose of parametric analysis of design options on Revit models. Daylighting in Revit is performed with a plugin called Lighting Analysis for Revit (LAR), which uses Autodesk 360 Rendering to expose electric and solar lighting results directly on the Revit model. LAR was launched in 2014 but then became a part of Insight360 in 2015. Insight allows you to choose from either the DOE2 or EnergyPlus engines for energy simulation. An updated version of Insight360 for Revit 2018 added annual daylighting capabilities and LEED V.4- option 1 compliance report.

Table below explains the cost of each simulation tool.

Table 1 Basic information for simulation tools

TOOLS	VERSION	COST (SINGLE USER)[1]	OTHER COSTS
Design-Builder	5.2 Beta	$2,699	None
DIVA for Rhino	4.0	$950	Rhino $995
Honeybee	0.6	Free	Rhino $995
Insight360	Revit 2018 plug-in	Free (for Revit users)	Revit $2,000 (annual fee) + Cloud credits for daylighting[2]

1. Prices are in US Dollars

2. Cloud credit cost is based on square foot of model and users are charged for each single iteration. With this method, daylighting could be quite expensive for large projects.

GEOMETRY MODELLING

This section explains geometry modelling in the studied tools. It also investigates the capability of the tools to import Green Building XML (gbXML), which is an industry supported schema that allows disparate 3D building information models (BIM) and architectural/engineering analysis software to share information with each other. The ability to import gbXML particularly benefits the projects with Revit architectural models. However, the architectural Revit model should undergo some processing and modification prior to import to ensure that spaces are appropriately defined and a useful gbXML file can be generated out of an architectural Revit file. Drawing a new, simplified Revit model on top of the architectural model could be a solution to successful export of gbXML file from Revit.

DesignBuilder: DesignBuilder has a built-in tool to create the geometry. Furthermore, it is capable to import gbXML files. Architectural Revit models could be used for energy and daylighting analysis after some processing in Revit.

DIVA: The geometry should be created in Rhino for DIVA. DIVA is not capable of importing gbXML files, however, Revit architectural models could be imported to Rhino. The only problem is that glazing surfaces should be flattened from 3D to 2D surfaces for analysis in DIVA. This problem is resolved by using script provided by DIVA development team that flattens 3D windows to 2D surfaces.

Honeybee: The geometry should be created in Rhino, and captured via the "Brep" command by Grasshopper in order to be translated into analysis surfaces. gbXML import is in progress and it will be available in the near future.

Insight360: Inisght360 is an add-in tool for Revit, which works smoothly on architectural models created in Revit. Insight360 analysis tool does not work on geometries exported from other 3D modelling tools to Revit.

Separate Models for Daylighting and Energy Simualtion

Some tools require creating two separate models for energy and daylighitng while others allow peforming both analyses in one model. In DesignBuilder, Honeybee and Insight 360, the same geometry could be used for both daylighting and energy simulation. In DIVA, a separate geometry is needed for energy modelling.

DesignBuilder: In DesignBuilder, extra time is required for processing the architectural Revit model to be able to export it as gbXML. This gbXML model could be used for both daylighting and energy simulation in DB. For accurate daylighting simulation, some architectural details such as columns, window frame thicknesses, and interior ceilings should be added to the simplified model.

Diva: The benefit of having two separate models is that the energy model could be simplified with fewer details than the daylight model. The drawback is the extra time required to draw the second model and that the energy and daylight models are not connected. If one model is changed during architectural revisions, the other model is not automatically updated. As a result, extra time is needed to create and update the second model.

Honeybee: Honeybee introduces more flexibility for users; they can either pick the exact same surfaces for both simulations, or draw additional surfaces in Rhino to add the details they need, and select if only for daylighting simulation.

Insight360: The Revit architectural model is used for both simulations. However, extra time is needed for processing the Revit file for energy simulation.

Highlights of the aforementioned pros and cons are included in Table 2.

Table 2 Comparison of geometry modelling

TOOL	3D MODEL	IMPORT GBXML	NEEDS SEPARATE MODELS	PROS/CONS
DB	Revit	Yes	No	Con: Extra time for processing Revit model
DIVA	Rhino	No	Yes	Con: Extra time to draw a second model
HB	Rhino	Yes (in process)	No	Pro: Flexibility; one or two models could be used
Insight	Revit	Yes	No	Con: Extra time for processing Revit model

Air Walls

Air walls are interior, virtual partitions created to separate thermal zones for energy modelling purposes. However, they are not needed in daylighting analysis and it is necessary to allow daylight penetration into the building. Air walls are key elements for successful energy and daylighting simulation, and they become an important issue when a single geometry is used for both simulations, in DesignBuilder, Honeybee, and Insight 360.

DesignBuilder: In DesignBuilder, it is possible to create "Virtual Partitions", which are synonymous to air walls. Air wall become a problem when gbXML models are imported to DesignBuilder from Revit. In Revit, there is an option to create air walls via "Space Separators". However, the gbXML file does not convey that information to DesignBuilder. Thus, Space Separators are imported as actual opaque walls. To solve this issue, users should pick each air wall, one by one, after importing to DesignBuilder and change them to Virtual Partitions.

Honeybee: To create air walls in Honeybee, a specific command should be used, which is called "Solve Adjacency". The process of selecting each air wall in the model is not convenient in Honeybee, particularly for large projects with multiple interior spaces.

Insight360: Air walls are drawn as Space Separators in Revit and they allow natural light penetration in LAR daylight analysis.

CONSTRUCTION MATERIALS

In DesignBuilder, construction materials for both energy and daylighting simulation are defined at once; the same material is used for both simulations. However, in DIVA, Honeybee and Insight360, thermal properties of materials for energy simulation are specified separately from the surface reflectance for daylighting simulation. The benefit of defining materials in one place is obvious; users cannot mistakenly select two set of properties for a surface.

In *DesignBuilder,* users can pick a construction assembly from an extensive library of templates, including ASHRAE 90.1 2007 and 2010. In addition, customized construction materials could be created using EnergyPlus "Layer Method". For daylighting purposes, users should set the Visible Absorptance of the innermost layer to the required level. Visible Reflectance of the interior surfaces is automatically calculated by 1 - Visible Absorptance. There is no need to define materials separately for daylighting and energy simulation. One limitation in DesignBuilder is that users cannot see the Visible Reflectance values in DesignBuilder GUI.

In *DIVA*, construction materials should be selected from predefined lists for both energy and daylighting simulations. For daylighting, a list of typical construction materials is available. For energy modelling, the list of materials is very limited, and it provides a few options from ASHRAE 2007 and 2010 baseline materials. The list of glazing materials also does not state the U-values or SHGC of glass options.
To add customized construction materials in DIVA, scripting is the only option. Users should write scripts of new materials in EnergyPlus (idf) and Radiance format and add them to the material folder located in the main directory of the program.

Honeybee, provides an extensive library of materials, which could be filtered based on code and climate zone. In addition, "Create Eplus Construction" command allows users to create and customize any desired type of construction in EnergyPlus format.
For daylighting simulation, the desired level of surface reflectance should be defined separately. Users do not need to have the knowledge of scripting materials in Radiance format.

Insight360 provides a long list of pre-defined construction materials with U-values, R-values specified. However, users are limited to choose a single construction type for the whole building. The other limitation is that users are not able to create a customized construction material through insight 360 GUI. The only option for users is to pick the closest material to the desired level of performance or script a new material, which requires advanced scripting knowledge in Revit. Although Insight 360 has an extensive list of materials, it does not refer to ASHRAE 90.1 prescriptive U-values and ASHRAE climate zones.

For daylighting in Revit LAR, materials should be defined separately under materials' rendering settings; Visible Transmittance (T-vis) of glass and Visible Reflectance of surfaces should be defined by identifying their colour in RGB (Red Green Blue) format under Custom Colour parameter in Material Appearance. Users could use a simple calculation Excel sheet, created by

Autodesk, to translate T-vis of glazing materials and surface reflectance of opaque materials to RGB colours. One current limitation of LAR is modelling translucent glass since the diffusing effect of light passing through frosted or fritted glass is not supported.

DAYLIGHTING SIMULATION INPUTS

Simulation Engine

RADIANCE (Ward, 1994) is the lighting engine used in all the studied programs except for Insight360. Lighting Analysis for Revit (LAR) is a cloud-based simulation tool in insight360 that has a built-in engine, which has been tested and proved close to Radiance results (Jacob et al., 2015).

Table 3 Daylighting simulation engines

TOOL	POINT-IN-TIME	CLIAMTE BASED
DB	Radiance	Daysim
DIVA		
HB		
Insight	Lighting Analysis for Revit (LAR)	

Radiance Parameters

DesignBuilder, DIVA, and Honeybee allow users to define accuracy of simulation by setting radiance parameters through their GUI. Insight 360, however, defines accuracy (Resolution) level by defining the analysis grid size. There are two options of 12-inch grid and 72-inch grid provided for users.

Weather file

In all programs, weather data of the site location should be defined in TMY/TMY3 format.

Sky Condition

All the tools are possible to model CIE Standard sky conditions (e.g. sunny, overcast, and uniform skies). DIVA, Honeybee, and Insight360 are also possible to model Perez Sky, which is a climate-based sky specific to a location. In DesignBuilder, it is not possible to model Perez Sky for daylight simulation.

Analysis Grid and Daylight Sensor Location

Analysis grid is the work plane of interest. It should be defined for both single-point-in-time and annual daylight analysis. Daylight sensors are specific to annual daylighting. They are analysis nodes within the grid, where hourly illuminance values are calculated per year. While analysis grids and analysis nodes could be picked in some programs, they are automatically chosen without user's control in other programs.

The benefit of picking analysis grid is saving time, particularly for annual daylighting simulations, which takes significantly longer than a "point-in-time" simulation. Users can avoid running timely analyses for the whole building if they are interested in only one space.

The benefit of picking specific nodes within the work plane as daylight sensor is that users can replicate the exact location of sensors in a real building.

DesignBuilder: In DesignBuilder, users can neither pick analysis grids nor can they pick sensor locations. Annual daylight analyses run for the whole building, and on all the grid nodes, automatically; users should only define the desired height of nodes above the floor, grid size, and grid offset from walls.

DIVA and *Honeybee*: Users can pick one or multiple analysis grids in these programs and they can choose daylight sensor locations for annual daylight simulations. Height of the analysis grid and distance between calculation nodes should be entered in meters. In DIVA, the grid is automatically created with a 0.20 m (0.65') offset from the walls, whereas in Honeybee, the grid is created without any offset.

In *Insight360*, users cannot draw an analysis grid. Instead, they can choose a "Level" from the Revit model, or the whole building for analysis. To perform analysis for a specific room, users should create a new "Level" and draw a surface on top of it at a desired height. In Insight360, it is not possible to pick nodes within the space to define the location of sensors for annual analysis. There is no option to choose the dimension of the analysis grid in LAR, the analysis grid has default dimension of 1'x1' for point-in-time daylight simulation and 2'x2' for annual daylight simulation.

DAYLIGHTING SIMULATION OUTPUTS

Point-in-time Daylighting

Capability of programs to generate the following metric were investigated:

1. Average illuminance in a space
2. Percentage of floor area with illuminance levels between 300 lx to 2000 lx.

In addition to these two metrics, other graphical and numeric outputs of each program is explained in this section.

DesignBuilder:

Graphic Outputs:

Illuminance maps for the building floors are generated in DesignBuilder. In order to change the key index for these maps, minimum and maximum Daylight Factor should be changed rather than illuminance levels in the settings, which is rather inconvenient for users.

Numeric Outputs:

DesignBuilder creates a table for building spaces. This table includes useful information, including:

- Space Area
- Floor area above threshold (Area/%)
- Illuminance (Min/Max)
- Daylight factor (Min/Max/Avg)
- Uniformity Ratio (Min/Avg)
- Uniformity Ratio (Min/Max)

However, there is no data about average illuminance levels in each space, nor is there data about floor areas below a desired threshold.

Another limitation is that it is not possible to access illuminance data for analysis nodes. In addition, it is not possible to plot node values on the floor plan.

DIVA:
Graphic Outputs:
In addition to illuminance maps, DIVA automatically populates useful results, illustrated in the Figure 1, when daylight simulation is complete.

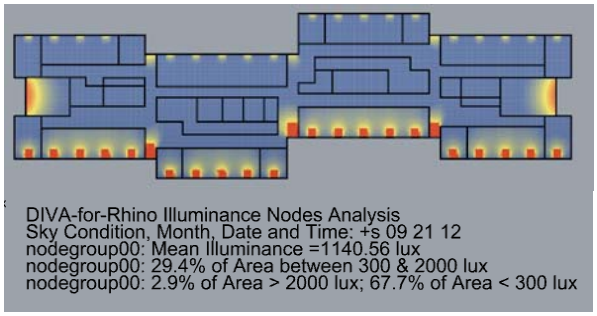

Figure 1 Automatic numeric results created along with graphical maps in DIVA

Numeric Outputs:
In DIVA, it is possible to plot node values on floor plans. Simulation results, including node values are automatically saved in the project folder. These results are in RGB value format, which could be translated into illuminance values at each node of the analysis grid with the use of a conversion formula.

Honeybee:
Graphic Outputs:
Honeybee can create point-in-time illuminance maps in addition to many other graphic options, such as 3D graphs. This tool is very flexible in terms of graphic display options and it is possible to adjust the index key as users desire.
Numeric Outputs:
Average illuminance, percentage of floor area within a specific range, and many other metrics could be found by using Honeybee outputs. In addition, Grasshopper's "Math" functions could be used for multiple data analysis without the need to export the results to another software. Node illuminance values could also be exported in Excel. Furthermore, it is possible to see node values on floor plans in HB.

Insight360:
Graphic Outputs:
Illuminance Map are created in Insight360 with a wide range of analysis display styles; one of which is called "Radiance" style for the desired illuminance threshold between 300 lx and 2000 lx. The major benefit of this setting is to customize the colours and the legend for displaying the results.
One drawback is that currently, there is no way to save multiple graphic outputs; only the last analysis results are saved within the Revit model.
Numeric Outputs:
In Insight360, it is possible to export the results to Excel and perform further data analysis. But the results are not categorized based on spaces, as they are in DesignBuilder, nor they are associated with a node name. In other words, it is not possible to correlate the results with the floor plan.

Annual Climate-based Daylighting

For annual daylighting, this report explains which simulation tools provide simulation with Daysim, which is a Radiance-based daylighting analysis software (Reinhart and Walkenhorst, 2001).
The following metrics were targeted:

1- Daylight Autonomy (DA): defined as percentage of the time (working year) when a minimum threshold of light could be maintained by natural light alone (Nabil, et al. 2006) in a selected space.
2- Useful Daylight Illuminance (UDI): percentage of the operation time, when illuminance values between 100 lx to 2000 lx are received by natural light in a space (Nabil, et al. 2006).
3- Spatial Daylight Autonomy ($sDA_{300/50\%}$): sDA is a metric used for LEED V.4- Option 1 for Daylight credit. It demonstrates percentage of a space where minimum 300 lx illuminance is received by natural light for at least 50% of the working year.
4- Annual Sunlight Exposure ($ASE_{1000/250}$): ASE is another LEED V.4- Option 1 metric for used to identify possibility of glare in a space. It defines what percent of a space receives illuminance values higher than 1000 lx for more than 250 hours per year.

DesignBuilder:
Graphic Outputs: It is possible to generate color-coded work-planes with DA, UDI, sDA and ASE results for the whole building and for each space.
One limitation is the fact that node values could not be plotted on the work-plane.
Numeric Outputs:
DesignBuilder generates a table for each building level, which includes space names, area of space, % of area with sDA and ASE within the threshold. This table could be exported as .csv file. In Excel, further analysis could be performed; spaces that fail to meet the criteria could be identified conveniently.
One limitation of DesignBuilder is that node values are not accessible. Having node values would help further to identify points of failure in spaces.

DIVA:
DIVA is capable of annual daylighting simulation with DAYSIM. It is also possible to generate LEED V.4-Option 1 metrics in DIVA.
Graphic Outputs: In DIVA, it is possible to generate color-coded floor plans and 3D views of spaces with DA, UDI, sDA and ASE results. In addition, DIVA automatically creates a report after annual daylighting, which includes hourly graphs of lighting schedules with and without daylighting control in a space.
Numeric Outputs:

DIVA creates numeric outputs such as Mean Daylight Autonomy, UDI, Mean Annual Daylight Factor, $sDA_{300/50\%}$, ASE, and annual occupancy hours.
In addition, DIVA automatically stores DAYSIM results in .CSV file format. For each hour of a year, occupancy rate, illuminance level, and % of electric lighting that is turned on is generated.

Insight360:
Graphic Outputs: It is possible to generate Daylight Autonomy, UDI, sDA and ASE results in Insight360.
Graphic Outputs: Detailed room by room results for sDA and ASE are provided in a Revit schedule entitled "Lighting Analysis Room Schedule". It is possible to export the results to Excel as well.

Daylighting Simulation Computation Time

In DesignBuilder, DIVA, and Honeybee, computation Time is reasonable; it depends on desired accuracy level. In terms of computation times, all programs took one or two minutes to run a single time daylight analysis, except for Insight360, which had an average simulation time of 20 minutes. Since the program is cloud-based, it might not be exactly comparable to a desktop, as simulations might take more time depending on the cloud traffic.

ENERGY SIMULATION

EnergyPlus engine is provided for energy simulation in all four programs. *DesignBuilder* uses v-8.6, *DIVA* uses v-7.2, *Honeybee* and *Insight360* use v-8.5 of EnergyPlus. *Insight360* provides the option to choose DOE.2 or EnergyPlus engine for energy simulation.

HVAC System Options

In general, within the studied tools, energy simulation is possible in two levels: Simple and Detailed.
In the Simple Method, mechanical equipment and heating/cooling loops are not modelled. The EnergyPlus Ideal Loads Air System is used to calculate heating and cooling loads. This system operates ideally; it provides enough hot/cold air to meet heating and cooling loads calculated in spaces. Energy consumption is calculated by using the efficiency rate defined for heating/cooling.
In the Detailed Method, it is possible to model plants, mechanical equipment and loops. It is possible to customize system settings to exactly match the mechanical systems that operate within the buildings. Only with Detailed Method, accurate energy consumption of the building could be estimated.
The benefit of Simple Method is that it allows users with rudimentary knowledge about mechanical systems to understand the relative impact of daylighting on the thermal loads of a building. However, the Simple Method lacks the level of accuracy required for estimating energy consumption in different design scenarios.

DesignBuilder: DesignBuilder provides both Simple and Detailed HVAC Method for energy simulation. In the Simple Method, users identify heating/cooling efficiency factors applied to Ideal Load System and setpoint/setback temperatures.
In the Detailed Method in DesignBuilder, it is possible to create advanced and complex HVAC systems. Users can graphically view and customize mechanical system components.

DIVA: DIVA for Rhino is limited to a single zone thermal analysis with EnergyPlus. Instead, DIVA for Grasshopper should be used to preform multi-zone energy simulation (this report only focuses on DIVA for Rhino workflow).
DIVA provides a simple level of energy simulation with EnergyPlus Ideal Loads Air System.

Honeybee: Honeybee does not provide a detailed level of energy simulation; however, it enables more EnergyPlus capabilities than DIVA. In addition to Ideal Loads Air System, Honeybee enables creating ASHRAE 90.1 Appendix G. "Baseline HVAC System Types". It is possible to change some EnergyPlus settings in these systems in Grasshopper with Honeybee. However, it is not possible to create customized and complex mechanical systems with Honeybee. It is not possible to graphically see heating/cooling loops and equipment. Not all the parameters in EnergyPlus could be changed in Honeybee.
One option for users for detailed HVAC modelling is to export the model to OpenStudio and build on their model and advance their HVAC systems.

Insight360: Insight360 provides a simple level of energy simulation, but with more HVAC system options than Ideal Load Air Systems. Advanced Energy Settings in Insight360 GUI provides a dropdown menu for users to pick an HVAC system type and system efficiency. Figure 2 shows available HVAC system options.

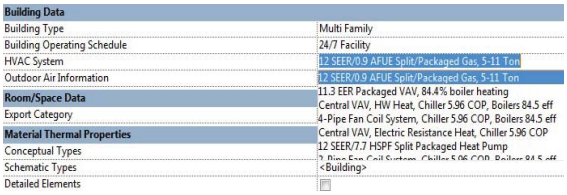

Figure 2 HVAC systems options in Insight 360

HVAC systems options are limited and users cannot change system parameters, including the efficiency rates. Customization and creating advanced mechanical systems are not possible. No graphics are provided to see/edit HVAC equipment and heating/cooling loops.
One option for users for detailed HVAC modelling is to export the model to EnergyPlus and edit the model.
Table 4 summarizes HVAC systems options in the tools.

Table 4 HVAC systems options

TOOL	HVAC SYSTEMS OPTIONS
DB	• Provides both simple and detailed HVAC methods • Includes templates for ASHRAE Baseline Systems • Includes templates for many other HVAC systems
DIVA-Rhino	• Only capable of E+ Ideal Load System
HB	• Does not provide detailed HVAC systems • Includes templates for ASHRAE Baseline Systems • Possible to customize some HVAC systems' settings
Insight	• Does not provide detailed HVAC systems • Includes a limited number of common HVAC systems in the industry without reference to ASHRAE Baseline Systems • Not possible to customize HVAC systems

HVAC Zoning

Zoning the spaces based on the mechanical units, which are serving them is important for accurate estimation of energy consumption in buildings.
DesignBuilder: HVAC zoning is only possible in Detailed HVAC Method in DesignBuilder. In the Simple Method, only one system is defined and assigned to the whole building.
DIVA: HVAC Zoning is not needed for a single zone.
Honeybee: In Honeybee it is possible to select several spaces served by a single mechanical equipment and group them as a single HVAC zone. However, performing a detailed HVAC zoning is not an easy task and it is not user-friendly. For buildings with numerous mechanical equipment, HVAC zoning is rather an arduous task.
Insight 360: only one mechanical system is assigned to the whole building; HVAC zoning is not possible in Insight360.

Internal Loads and Building Schedules

Occupancy schedule, occupant density, outdoor air flow rates, lighting power density (LPD), lighting schedule, equipment power density, equipment use schedule are important factors to estimate internal loads in a space.

DesignBuilder: By choosing an "Activity" template, all building schedules and internal loads are assigned to that space. ASHRAE 90.1-2007, 2010 and ASHRAE 60.1 code requirements are available in predefined templates. One "general" template is assigned to the whole building in DesignBuilder; other templates for different space types could be assigned space-by-space. Zone template assignment is convenient and efficient via the Filter tool, which searches for a keyword among space titles and assigns a template to all the selected spaces.
DIVA: For internal loads, users could specify occupant density, LPD, equipment power density, and air change per hour in DIVA GUI. Building operation schedules can be selected from a limited number of options. It is not possible to customize occupancy schedules through the DIVA GUI. It is not possible to differentiate equipment schedules from occupancy schedules; only one schedule is defined for the entire building operation, which is used for both equipment load and occupancy. An option for users to create customized settings is to change .idf scripts in the main directory of DIVA, which requires knowledge of E+ and scripting.

HoneyBee: Honeybee provides templates for thirteen major building types with reference to ASHRAE standard for occupancy rates, airflow rates, and LPDs. It is also possible to customize all of the inputs for internal loads. For schedules, Honeybee provides an extensive library of schedules written in EnergyPlus format. In addition, any desired schedule could be created in the Grasshopper environment via math functions.
However, assigning zone templates to spaces is not an easy task in Honeybee particularly in buildings with multiple space types. Searching through spaces based on this title or location is not possible. Users should pick each single space manually and assign the appropriate zone template.

Insight360: In Insight360, it is possible to assign a template for the whole building via the Insight GUI, or assign them space by space in the Revit geometry.
In space-by-space method, users can pick a space type from a predefined list for each space. It is also possible to change a few inputs such as occupancy rate, ventilation, and operation hours in Revit window. Existing space types in Revit does not refer to ASHRAE Standard. List of Space Type Data for Energy Analysis is provided in Autodesk Revit website.
Assigning zone templates to spaces is a difficult task in the space-by-space method in Revit. There is no searching or filtering tool to help users pick spaces with the same function easily in Revit.

Lighting Schedule and Daylighting Impact on Energy

In some of the studied programs, detailed daylighting schedule generated by daylighting simulation engine is linked to energy modelling. The benefit of this linkage is highly accurate estimation of electric reduction due to daylighting in spaces during whole building energy simulation.

Table 5 Radiance daylighting results incorporation into energy analysis

TOOL	RESULTS LINKED	PRO/CONS
DIVA	Yes	Pro: Highly accurate estimation of daylighting impact
HB	Yes	
DB	No	Con: Underestimation of daylighting impact by the use of in-built E+ engine for daylighting
Insight	No	

DesignBuilder: In DesignBuilder, energy simulation is totally disconnected to daylighting simulation with RADIANCE engine. For energy simulation, the built-in engine in EnergyPlus, called DElight, calculates daylighting.

DIVA: Lighting schedules are defined differently in DIVA. Lighting schedules are detailed schedules generated by DAYSIM from annual daylighting simulation. Energy simulation in DIVA is linked to the daylighting simulation results generated by DAYSIM.

Honeybee: Similar to DIVA, in Honeybee it is possible to use the detailed lighting schedule generated by DYSIM in energy simulation and accurately account for the impact of daylighting in terms of electric lighting reduction (see Figure 3).

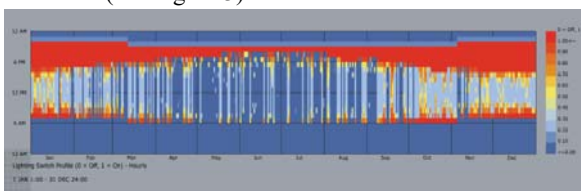

Figure 3 DAYSIM- based lighting schedule in Honeybee

Insight360: Daylighting simulations with LAR are totally disconnected from energy simulations in Insight360. Based on the engine picked for energy simulation, the built-in tool in DOE.2 or EnergyPlus is used for accounting the impact of daylighting in energy simulation.

CONCLUSION

Table below summarizes pros and cons of the simulation tools studied in this paper.

Table 6 Summary of pros and cons

TOOL	PROS	CONS
DB	- Detailed HVAC design option with user-friendly GUI - Quick and easy single-point-in-time Radiance DL analysis	- Knowledge about mechanical plants and heating/cooling systems, HVAC loops, system control types and operation
DIVA-Rhino	-Quick and easy Radiance single point and annual daylighting with user-friendly GUI - Integrated DL and energy for s single zone	- Lack of advanced HVAC design and energy simulation settings - Lack of multizone thermal analysis
HB	-Free -Flexibility - Integration of DL and energy for multiple zone	- Requires Grasshopper background - Complexity of the tool in multizone thermal settings - Lack of a user-friendly GUI for energy simulation
Insight	- Quick energy analysis with no background required - Quick and user-friendly single-point daylight analysis	- Lack of advanced HVAC design option - Lack of connection between daylighting and energy simulation

Although each tool offers special features for daylighting and energy simulation, it is concluded that none of them provide a convenient and user-friendly process for integrated daylighting and energy analysis for medium to large projects with the detail required at design development (DD) and construction document (CD) phases of design.

DesignBuilder is unique for its HVAC GUI for EnergyPlus engine and importing gbXML models is a smooth process. However, annual daylighting simulation with DAYSIM is disconnected from energy simulation.

Honeybee has extensive potential, as it provides flexibility and customization for inputs and outputs, but the tool needs prior experience with Grasshopper. Detailed level of energy modeling and gbXML import is not possible.

DIVA for Rhino is very limited in terms of energy simualtion. Only a single zone thermal simulation could be performed and energy inputs options are limited via DIVA GUI. Additionally, DIVA is not capable of importing or exporting gbXML files.

Insight360 is a useful tool for Revit users; however, LAR daylighting engine is not connected to energy simulation. Detailed energy simulation is not possible.

In the future, the results of these tools will be compared by simulating an example project. The authors would like to investigate daylighting and energy modelling workflow in other programs such as IES and OpenStudio.

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