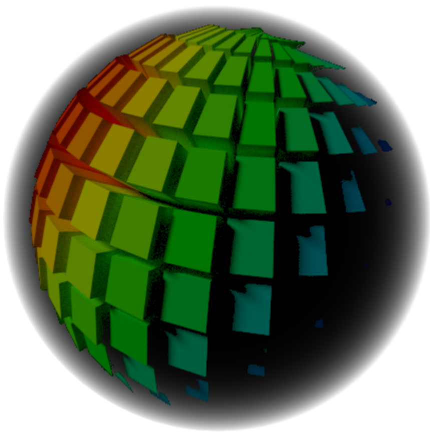
Simulations and Visualisations with the VI-Suite

For VI-Suite Version 0.3



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1 Introduction

The VI-Suite is an open-source add-on to the 3D modelling and animation package Blender that provides a set of tools for the analysis of environmental factors within and around buildings. It uses Blender's node system (figure 1) to provide a user interface that allows quick and custom analyses to be created. As of VI-Suite version 0.3 nodes exist for GIS height map import, sun path analysis, wind rose display, shadow studies, lighting metric prediction, thermal performance prediction and advanced airflow network creation. The lighting and energy analyses are achieved with the two main VI-Suite components: LiVi, which acts as a pre/post-processor for the Radiance lighting simulation suite and EnVi, which does the same for the EnergyPlus v8.4 thermal simulation engine.

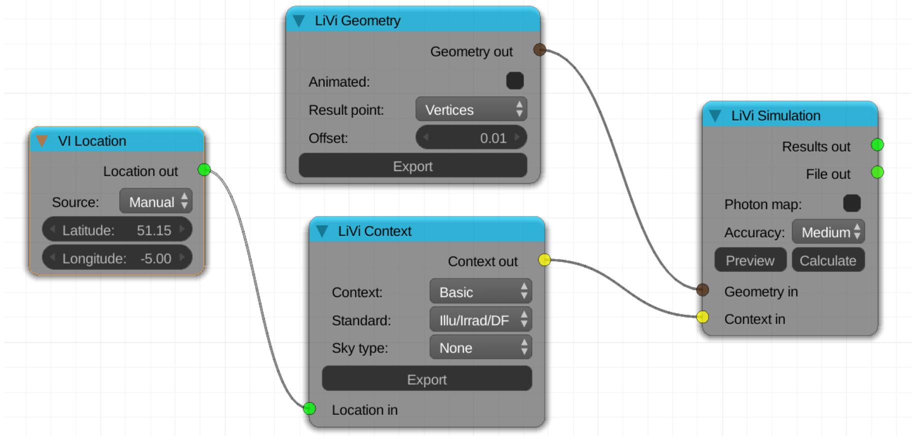


Figure 1: Blender nodes

2 Installation

Prepackaged VI-Suite zip files for Windows and Mac OS X can be downloaded from the VI-Suite website http://arts.brighton.ac.uk/projects/vi-suite/downloads. The zip file can be extracted to anywhere on the host computer and the Blender executable run from the created directory.

As there are so many different Linux distributions, and the required software installation is relatively simple, no complete packaged file is provided for this platform. A VI-Suite zip file, which includes all the VI-Suite specific files can however be downloaded from the VI-Suite website and moved to the Blender addons directory.

If a manual installation of the separate components is preferred, platform specific installation guidelines can be found below.

2.1 OS X

The VI-Suite has been tested on OS X Version 10.10 (64bit).

First download Blender from http://www.blender.org/download and install. Run Blender once and select "File" - "Save Start Up File" to make sure the Blender configuration directory is created at /Users/*user-name*/Library/ Application Support/Blender/*blender_version* where *user-name* is your user-name and *blender_version* is the version of Blender downloaded (currently 2.76). Create within this directory a "scripts" directory, and within this an "addons" directory (all lowercase).

The VI-Suite Python files are available as a down-loadable zip file from the VI-Suite website which can be found at (http://arts.brighton.ac.uk/projects/vi-suite/downloads. The vi-suite folder within the zip file should be placed in the /Users/*user-name*/Library/Application Support/Blender/ *blender_version*/scripts/ addons/ folder created earlier.

Download Radiance from https://github.com/NREL/Radiance/releases/ and run the Radiance installer. The VI-Suite assumes Radiance is installed to the folder locations /usr/local/radiance. A recent version of Radiance (5.0 or above) is required.

Download and install EnergyPlus v8.4 from https://github.com/NREL/EnergyPlus/releases. The VI-Suite assumes EnergyPlus is installed in the /Applications/EnergyPlus-8-4-0 directory.

As of Blender version 2.76, Numpy is included with Blender but a number of other dependencies, namely pyparsing, six, sip, dateutils, distutils and pylab, are required for full matplotlib functionality. Installing all these dependencies is troublesome but the easiest method would appear to be installing a Python 3.4 distribution such as Anaconda https://store.continuum.io/cshop/anaconda/ and copying the relevant files to Blender's Python folder. If matplotlib still does not work try typing *import matplotlib.pyplot as plt* in Blender's Python command window. Any error message should say which Python library is missing.

It is also advisable to use a three-button mouse, which is set up as a three button mouse in OS X.

2.2 Windows

VI-Suite has been tested on a 64bit Windows 7 system, although the Radiance and Blender binaries are both 32bit and should run on older 32bit Windows versions. First download the Blender zip file from http://www.blender.org/download. The folder within this zip file can be moved to anywhere on your system as long as there are no spaces in the full directory path. The folder is subsequently referred to here as the *blender_folder.* Run Blender once and select "File" - "Save Start Up File" to make sure the Blender configuration directory is created at
`C:\Users\`*`user-name`*`\AppData\Roaming\Blender Foundation\Blender\`*`blender_version`* where *user-name* is your user name and *blender_version* is the version number of the downloaded Blender version (2.76 at the time of writing). Create within this directory a "scripts" directory, and within this an "addons" directory (all lowercase). Then download Radiance 5.0 from https://github.com/NREL/Radiance/releases/ and install. Vi-Suite assumes that Radiance is installed in the C:\Program Files(x86) \Radiance folder for 64bit windows and C:\Program Files\Radiance for 32bit windows. A recent version of Radiance (5.0 or above) is required.

Download and install EnergyPlus v8.4 from https://github.com/NREL/EnergyPlus/releases. The default installation location should be chosen which the VI-Suite assumes is in C:\EnergyPlusV8-4-0.

From http://arts.brighton.ac.uk/projects/vi-suite/downloads download the VI-Suite Python scripts zip file. Inside the zip file is a folder called vi-suite, which should be moved to the C:\Users*user-name*\ Application Data\Blender Foundation\ Blender*blender_version*\scripts\addons\ folder created earlier.

As of Blender 2.76, Numpy is included within Blender's inbuilt Python installation. Installing matplotlib for plotting capabilities is, however, a little complicated. The best way appears to be to download a Python 3.4 environment like Anaconda and moving the required matplotlib components: PySide, dateutil, six, sip, PyQt4 and pyparsing to the relevant folder in *the blender_folder*\2.76\python directory. If matplotlib still does not work try typing *import matplotlib.pyplot as plt* in Blender's Python command window. Any error message should say which Python library is missing.

There is a bug in the interaction between Blender and matplotlib which causes Blender to crash if a png file is saved from a matplotlib window. Save a pdf or svg file instead.

2.3 Linux

VI-Suite has been tested on a 64bit Arch Linux installation. First install Blender, which is available though most Linux distributions package management system. Run Blender and select "Save Startup File" from the file menu to create a Blender configuration directory at
`/home/`*`user-name`*`/.config /blender/`*`blender_version`* where *user-name* is your user name and *blender_version* is the Blender version number (2.76 at the time of writing). Create within this directory a "scripts" folder and within this an "addons" folder.

The is available as a zip file from the VI-Suite website at
(http://arts.brighton.ac.uk/projects/vi-suite/downloads. Inside the zip file is a folder called vi-suite. This folder should be moved to the
`/home/`*`user-name`*`/.config/blender/`*`blender_version`*`/scripts/addons/` folder created earlier.

Download Radiance from https://github.com/NREL/Radiance/releases/ or from the host package management system and install to the default folder. The VI-Suite assumes that Radiance is installed in the /usr/local/radiance or /usr/share/radiance folder. A recent version of Radiance (5.0 or above) is required.

Download and install EnergyPlus v8.4 from https://github.com/NREL/EnergyPlus/releases. The default installation location should be chosen which the VI-Suite assumes is in /usr/local/EnergyPlus-8-4-0.

As of Blender version 2.76 Numpy is included with the Blender release but in general it is easier to install Python, numpy, matplotlib and the Python modules sip, six, dateutil, pyparsing and PyQt4 via the distribution's package management system, and removing the /usr/share/blender/*2.76*/python folder to force Blender to see the system Python installation.

2.4 All Platforms

Once the whole VI-Suite has been downloaded and installed, bug fix updates of the actual Python VI-Suite scripts can be downloaded checking out the code from the github repository. Go to
https://github.com/rgsouthall/vi-suite.v03 and click on the 'Download ZIP' button on the right. Bleeding edge code (and I really do mean Bleeding Edge) can be found in the v04 repository https://github.com/rgsouthall/vi-suite.v04 . Once the repository is selected the latest code can be downloaded with the zip link at the top of the github page.

3 Configuration

Running Blender launches the main Blender interface, which should look similar to the one shown in figure 2. The main window is the 3D view where the default cube, lamp and camera can be seen. Below this is the animation time-line, on the top right is the project outliner that contains a list of everything in the scene, and bottom right are the properties panels where many of Blender's options and functions reside. At the top of the properties panel window are tabs to control which panel is visible. The main panels used in the VI-Suite are the "Material" and "Object data" panels. Detailed instructions on how to use Blender are beyond the scope of this document, but there are excellent and free beginners documents available by James Chronister, available here and by John Blain, available here and good on-line video tutorials available here and here. In addition, there is a wealth of books [1, 2, 3], websites and You Tube and Vimeo videos dealing with many aspects of Blender's capabilities. The Blender Artists forum at http://blenderartists.org/forum/ is an excellent resource for finding out what other people are doing with Blender, and asking questions of knowledgeable users.

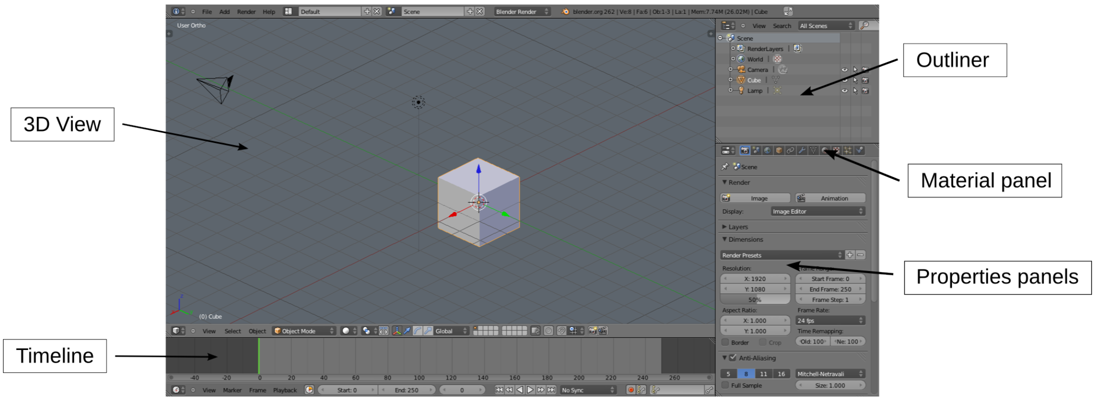


Figure 2: Blender interface

The VI-Suite is an add-on to Blender and will need to be activated on a fresh install. This can be done from Blender's user preferences. Go to "File" menu at the top of the 3D view and from the drop down list select "User Preferences". Along the top of the new preferences window there will be an "Addons" tab. Click on this and then scroll down and select the VI-Suite by clicking on the box on the right of the VI-Suite entry. It may take a couple of seconds for the box to show a tick indicating that the VI-Suite has been registered. There are other settings within the "User Preferences" that can be altered as desired, for example to control how the 3D view is navigated. The resources above contain sections on customising the Blender user interface. By default the 3D view can be rotated with the middle mouse button, zoomed with the mouse wheel and objects are selected with the right mouse button (it is recommended to change this to left mouse button select in the user preferences "Input" tab). Once the VI-Suite addon has been activated, and any other changes have been made, click "Save User Settings" to make these choices permanent.

Once the VI-Suite has been activated it sits within Blender's node editor. The Blender interface is, in general, what's called a non-overlapping interface i.e. interface areas sit side-by-side rather than on top of each other. Any area can be turned into any other area type by selecting the type from the drop-down menu at the left-hand side of the area's header bar, which sits either at the bottom or the top of each area. For example, the time-line can be turned into the node editor by selecting "Node Editor" in the drop-down menu in the very bottom left of the time-line area.

4 The Vi-Suite Interface

4.1 The Node System

The VI-Suite uses Blender's user customisable node system to provide a flexible user-interface. The node editor view (figure 3) can be panned with the middle mouse button and zoomed with the mouse scroll wheel. Nodes can be added, deleted, moved, re-sized, collapsed, grouped, linked and unlinked. Once a VI-Suite node tree has been created nodes can be added using the "Add" menu item at the bottom of the node editor. There are six node categories:

- Input nodes that import data into the VI-Suite
- Export nodes that export Blender information to a format that can be used for analysis
- Analysis nodes that run analyses
- Generative nodes that specify targets and geometry manipulation for Generative Design
- Display nodes that display the results of analyses.
- Edit nodes that can manipulate data

Some of these nodes are common to multiple types of analyses.

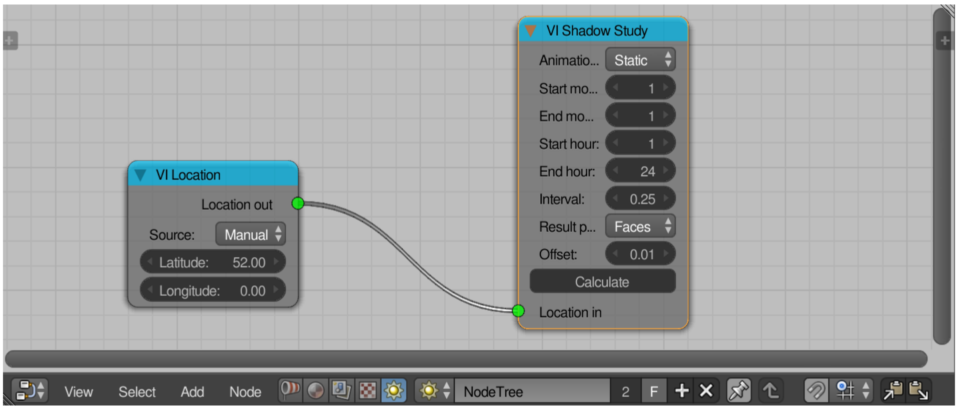


Figure 3: Blender node editor

Before any nodes are created the Blender file should be saved. The VI-Suite project directory will then be created in the same location as the Blender file is saved to, with the same name as the Blender file name.

Within the node editor VI-Suite nodes can be connected together to perform analyses. Once the node editor has been selected for an interface area, at the bottom of the node editor area will be a row of menu items and a row of icons (figure 4). The main VI-Suite node tree window is selected by selecting the sun icon in the icon row. Once the sun icon has been clicked press the new button on the right to create a new VI-Suite node tree. The "Add" menu entry allows the creation of nodes within the chosen, created node tree.

It should be noted that when switching between different node trees with the node tree icons, the active node tree in any node tree window will be forgotten, and must be selected again with the drop-down menu to the left of the "New" node tree button. A video showing activation and set-up of the VI-Suite can be found at *http://blogs.brighton.ac.uk/visuite/2015/10/22/vi-suite-v0-3-tutorial-1-activation*.

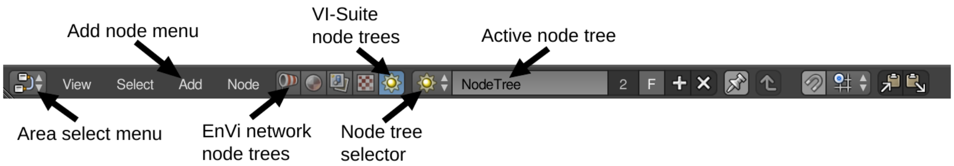


Figure 4: Blender node editor menus

Blender nodes can be scripted with Blender's Python scripting back-end and this allows some user-feedback features to be implemented. Nodes in general will be red if:

- The node contains a operator button which has not yet been pressed
- The options selected within the node are different to the selected options when the operator button was last pressed
- The options selected within the node are invalid within the context of the other nodes the node is connected to.

The node colour will revert to the general Blender theme colour if none of the above conditions are true and the node, in it's current state, is valid as a simulation component.

Links between nodes are also scripted so that only valid links can be made. If a link is attempted between two node sockets the link will immediately disappear if the connection is not valid. Sockets are generally coloured to show which one can be connected (red to red, yellow to yellow etc).

In addition to the VI-Suite nodes, visualisation options, when relevant, become available in the 3D view properties panel in the "VI Display" tab (section 4.2). These options are not presented as nodes as they influence the 3D view display, and therefore have to sit in the 3D view properties panel.

4.2 Visualisation panel

Control of the visualisation of results within Blender's 3D View is done within 3D view properties panel. This panel can be toggled on and off by pressing the "n" key with the mouse over the 3D view. Alternatively you should see a small "+" sign in the top right of the 3D view. Clicking on this will also open the 3D view properties panel. At the bottom of this panel is the "VI-Suite Display" tab (figure 5), which will get populated with visualisation options as they become available.

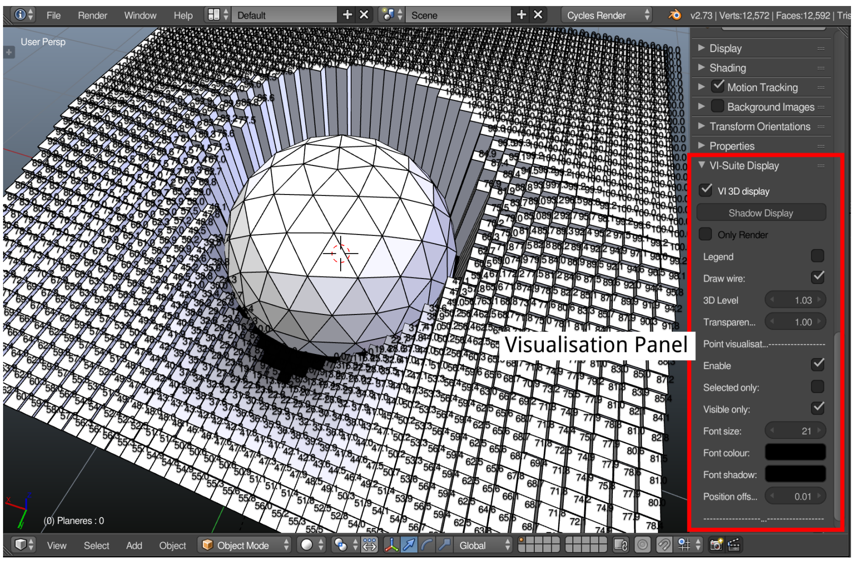
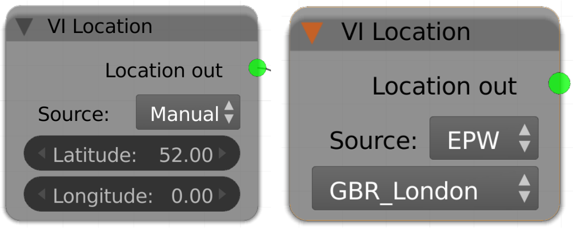


Figure 5: VI-Suite Display tab

4.3 Common Nodes

Common nodes are nodes that do not belong to any particular simulation pipeline.

4.3.1 The VI Location node



(a) (b)

Figure 6: VI Location node (a) with manual entry (b) sourcing EPW weather file

A VI Location node can be added from the "Add" - "Input nodes" menu entry. The Vi Location node sets the location of the context to be analysed in terms of latitude and longitude and, if required, hourly weather data from an EPW format weather file. This node is a required node for sun-path, solar shading, wind rose, energy and most lighting analyses.

The source of the information provided by this node can either be entered manually by the user (adequate for sun-path, solar shading and some lighting analyses) or generated from an EnergyPlus weather (EPW) file (required for wind rose, energy and CBDM analyses but can be used for any location based analysis type). This choice is made with the node's first drop-down menu. If the "Manual" option is chosen here then the user can enter site latitude and longitude (-180 to 180 degrees with West of the Greenwich meridian having positive values) in the two number dialogues. If "EPW" is chosen then a new drop-down menu appears with a list of registered EPW files. EPW files are registered by placing them in the "EPFiles/Weather" folder within Vi-Suite script folder, and restarting Blender. The EPW files should have a ".epw" or ".EPW" extension. A good source of EnergyPlus weather files is http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm, but they are a common format and can be found at many sites for a wide variety of locations.

The VI Location node has one output socket, a green "Location out" socket, which can connect to any green "Location in" socket.

4.3.2 The ASC Import node

ASCII formatted Esri Grid files are GIS data files which can represent ground elevation data in text file format. These files often have the extension .asc and are referred to as ASC files here. ASC files can be exported by the Edina DigiMaps web service that contain accurate terrain height data for the whole of the UK.

The ASC import node can be added via the "Input" nodes menu in the node editor. The node contains two toggle options and an operator button. The toggle options are:

- "single". If on, only the ASC file selected is imported. If off, all ASC files within the directory of the selected ASC file will be imported.
- "splitmesh". If multiple ASC file are imported this option creates separate meshes for each file. ASC files from DigiMaps are separated by the map grid squares selected for export. DigiMaps can also supply images of roads, building locations etc for each of these map grid squares and turning on "splitmesh" can make mapping these images to the geometry imported into Blender easier.

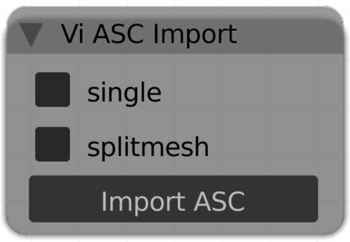


Figure 7: VI ASC import node

The operator button converts the ASC file into Blender co-ordinates and creates a mesh within the scene which accurately represents the ground heights in the ASC file. Once this geometry has been imported it can be subject to further analysis, for example a shadow study (section 4.4.3).

A render of the terrain around Mount Snowdon in Wales is shown in figure 8.

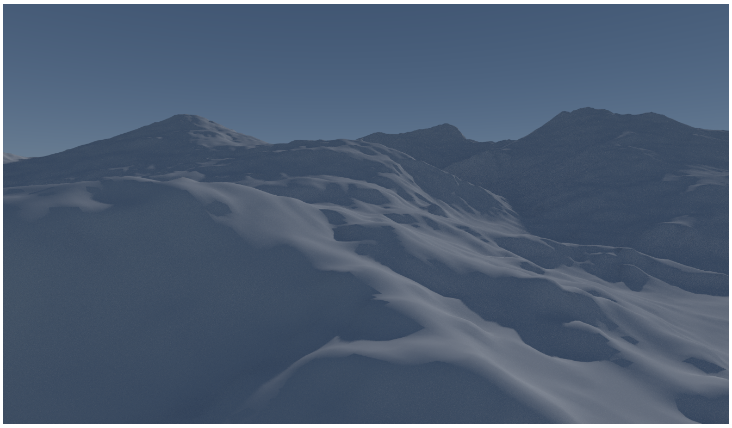


Figure 8: Render of ASC imported terrain height around Mount Snowdon.

4.3.3 The EnVi Results File node

The EnVi Results File node (figure 9) allows for the loading of a previously generated results file from an EnVi simulation for plotting. The node contains a file select button which opens up a file selection window to navigate to the desired file, a text box that shows the file name and path of the currently selected file, and a "Process File" button to convert the results file into data stored within the node. Once the "Process File" button has been pressed the "Results out" socket should become visible for connection to a VI chart node.

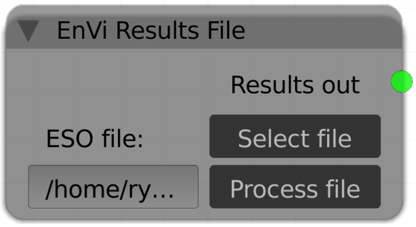


Figure 9: EnVi Results File node

4.3.4 The VI Chart node

The VI Chart node (figure 10) uses Matplotlib http://matplotlib.org/ to provide simple line plotting for certain types of data. As of version 0.3 this chart node can plot climate data from an EPW file selected within a "VI Location" node, and results data from an "EnVi Simulation" or "EnVi Results file" node. Up to three data sets can be plotted on the y-axis via a dynamic number of input sockets that get created as sockets are connected.

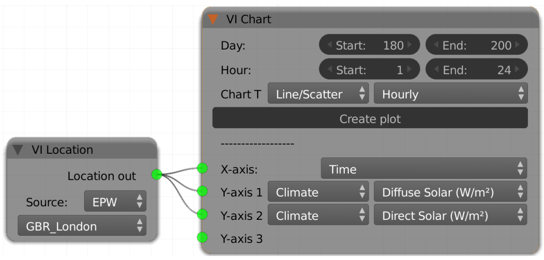


Figure 10: VI Chart node

Initially only the X-axis socket is exposed. Once this socket is connected a "Y-axis 1" socket is exposed. Once this socket is connected a "Y-axis 2" socket is exposed, which should again be connected to the same "Results out" socket. In total three "Y-axis" sockets can be exposed. All sockets should be connected to the same "Location out" or "Results out" socket.

Next to each connected socket, menu items will appear to select the type of data to plot on the axis. This contents of these menu items depends on the contents of the results embedded in the connected results node.

A "Create plot" button in the middle of the node creates the Matplotlib plot in a new window. Buttons within this new window allow some manipulation of the chart and export to image file. On Windows PNG export will crash Blender. Select PDF or SVG export instead. The options presented by the node are:

- Day - start and end day of the period to be plotted. Defaults to the total day range of the results connected to the sockets.

- Hour - start and end hour of the day period to be plotted.
- Chart type - Line/Scatter for line or scatter plots, and bar for bar charts
- Frequency - Hourly, daily, monthly results plotting

4.4 Specific Analysis Nodes

Analysis nodes can be found in the "Add" - "Analysis nodes" menu in the VI-Suite node tree. Analysis nodes initiate actual calculations. Some analysis nodes need to be part of a larger node set-up, for example LiVi and EnVi simulation nodes, whereas others represent a complete analysis, for example wind rose and shadow study nodes. These standalone analysis nodes are described here.

4.4.1 The Vi Wind Rose node

The VI Wind Rose node takes wind data from an EPW weather file and creates a wind rose plot. The "VI Wind Rose" node has one input "Location in" socket that connects to a VI location node "Location out" socket. As EPW data is required, EPW must be selected as a source of information in the "VI Location" node connected to the "Location in" socket. Once a valid "Location in" socket connection has been made a drop-down menu specifying the type of wind rose to plot (two types of histogram, and three types of contour, plot are currently available), two numerical input fields to specify the start and end month for the wind rose data, and one "Export" button are exposed. Upon pressing the "Export" buttons a new wind rose object is created within the Blender scene which can be scaled, moved or rotated as desired. Wind rose specific display options are also revealed in the "VI Display" tab (section 4.2).

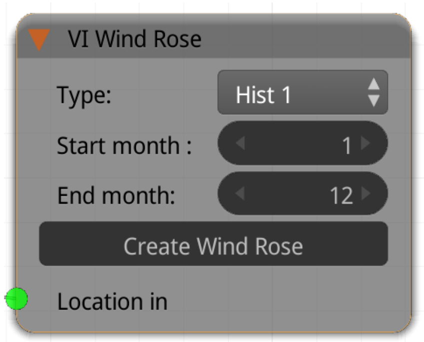


Figure 11: VI Wind Rose node

4.4.2 The Vi Sun Path node

The "VI Sun Path" node shown in figure 12 creates objects within the Blender scene for sun path visualisation (section 5.1). These objects include the sun-path mesh itself, sun lamp, sun mesh and sky mesh. These objects can be moved around the scene as desired. As the sun path analysis requires latitude and longitude data this node has one input socket "Location in" which connects to a "VI Location" node's "Location out" socket. As only latitude and longitude data is required either EPW or manual data input can be used in the "VI Location" node connected to the "Location in" socket. The node contains no options, simply a button, which is only visible once a valid "Location in" socket connection has been made, to create the sun-path geometry. Once this button is pressed, and the sun path objects created, options appear in the "VI-Suite Display" tab (section 4.2) to control the day, time and size of the sun path objects for real time visualisation of sun position.

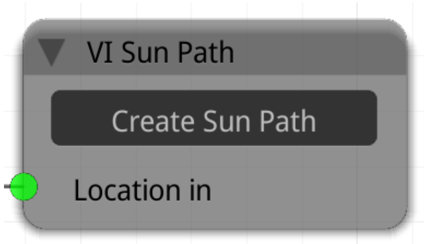


Figure 12: VI Sun Path node

4.4.3 The Vi Shadow Study node

The VI Shadow Study node (figure 13) grey-scale colours sensing geometry based on the proportion of time the geometry is exposed to direct sunshine assuming clear sky conditions. The calculation is done every specified interval during month and hour range specified if the sun is above the horizon. White means exposed to sunshine 100% of the time, and black 0% of the time. The node has one input socket; "Location in" which connects to a VI location node's "Location out" socket. Node options include:

- Animation - to specify whether geometry is animated or static
- Start & end month - to specify the month range
- Start & end hour - to specify the daily hour range
- Interval (in hours) - to specify the time between calculations (0.5 would be 30 minutes).
- Result point - to specify if the shadow sensing points are positioned at the face centre of vertices of the sensing object
- Offset - to specify the distance of the sensing point from the geometry (this is useful if the sensing mesh has non-planar faces that would place the centre of the face below the face surface)

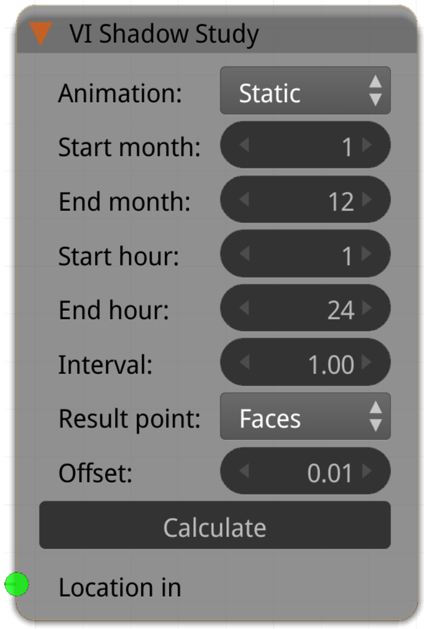


Figure 13: VI Shadow Study node

4.5 LiVi Nodes

The lighting analysis nodes control and specify a LiVi simulation for the prediction of lighting metrics. Most of the lighting analysis nodes ("LiVi Geometry", "LiVi Basic", LiVi Compliance" and "LiVi CBDM") can be added via the "Export nodes" menu. "LiVi Simulation" can be added from the "Analysis nodes" menu.

4.5.1 The LiVi Geometry Export node

The LiVi Geometry Export node (figure 14) exports Blender geometry and materiality to a format that can be understood by the Radiance lighting simulation suite. All unhidden lights, geometry and materials on the current Blender layer are exported and the Radiance description stored within the node. If the animation option is selected a description for each valid frame is written. The options within the node define whether the geometry is to be animated, the frame range for the animation and the point on any sensing geometry at which results will be calculated (vertices or faces). The node has one output socket that can connect to a 'Text' or 'Geometry in' socket.

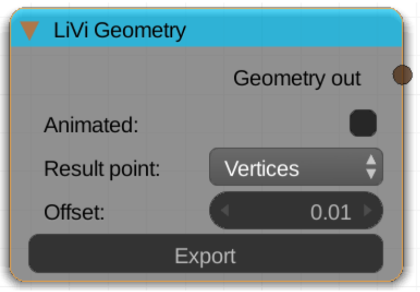
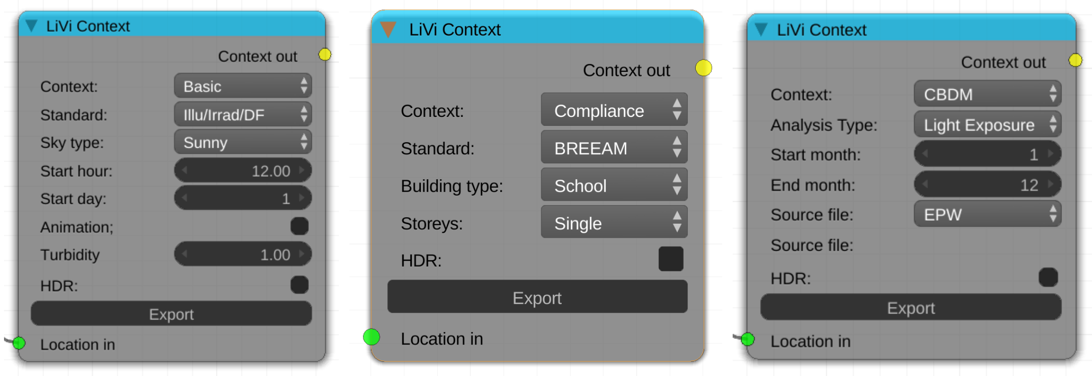


Figure 14: LiVi Geometry node

4.5.2 The LiVi Context node



(a) Basic analysis (b) Compliance analysis (c) CBDM analysis

Figure 15: LiVi Context node

The LiVi Context node (figure 15) controls the export of a lighting simulation context to a text format that Radiance can understand. In terms of a Radiance simulation, context means the type of sky the building is exposed to, the time of day and year and the metric to be calculated. On export the sky context is stored within the node. This node can create three different categories of sky context: 'Basic', for simple lighting metrics, 'Compliance' for checking against lighting standards (BREEAM and Code for Sustainable Homes are currently supported), and 'CBDM' for climate based daylight modelling.

The node has one input socket and one output socket. The input socket is a "Location in" socket for connection to a VI location node's "Location out" socket. The output socket is a "Context out" socket for connection to a 'Text' socket or a LiVi Simulation 'Context in' socket.

Node options are dynamic and presented only if appropriate for the type of analysis selected. Some of the options are:

- Analysis type - Basic:

    - Allows calculation of illuminance, irradiance, Daylight Factor & glare
    - Sky type options - Sunny, partly cloudy, cloudy, Daylight Factor, HDR & Radiance sky. The latter two allow the selection of an HDR panorama image or a Radiance sky description file respectively.
    - Animation options - Only available if a sunny, partly cloudy or cloudy sky is selected. If animation is chosen Blender animation frames will be created from the selected starting frame option (end frame is calculated automatically).
    - Time options Start hour/day (only available if a sunny, partly cloudy or cloudy sky is selected in the sky option) and end hour/day and interval (only available if animation is selected).

- Analysis type - Compliance:

    - Allows assessment of complaince against BREEAM and CfSH startndards

- Analysis type - CBDM:

    - Allows calculation of lighting and radiation exposure, daylight availability, useful daylight illuminance and hourly radiation.
    - Lux levels options - defines the lighting benchmark levels.
    - Source options - defines the type of climate data used to create the sky context.

- HDR: Exports an HDR panorama of the sky.

If valid socket input connections have been made an ’Export’ button will appear at the bottom of the node. Clicking this will export the context to Radiance format and stores it within the node.

4.5.3 The LiVi Simulation node

The LiVi Simulation node (figure 16) calls the rtrace component of Radiance to calculate the chosen metric on the sensing geometry. This node also shows the current range of frames for which a Radiance simulation will be conducted. It has two input sockets: "Context in", which accepts connections from another node’s "Context out" socket and "Geometry in" for connection to the "Geometry out" socket of a "LiVi Geometry" node. Once valid socket connections have been made the node options are exposed. The "Accuracy" menu controls the simulation accuracy, with more accurate values leading to longer simulation times. The options presented in this menu depend on the type of analysis being conducted: a LiVi Basic analysis presents "Low", "Medium", “High" and "Custom" options. LiVi Compliance and CBDM analyses give rise to "Initial", "Final" and "Custom" options. A "Custom" selection allows for the input of Radiance command line options into the exposed text box.

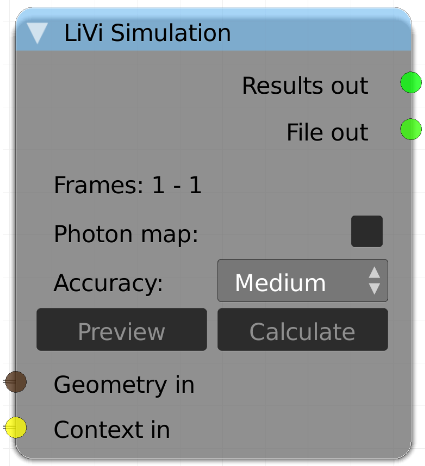


Figure 16: LiVi Simulation node

The node also contains options for Radiance’s new Photon Mapping capability (section 5.4.4). At least version 5 of Radiance is required to use Photon Mapping.

There are two buttons in this node: A “Preview” and a “Calculate” button. The "Preview" button brings up a Radiance rvu window and renders the scene, from the point of view of Blender’s camera, and the "Calculate" button initiates the rtrace simulation. When the "Calculate” button is pressed the Blender interface will lock up during the simulation unless a glare analysis was chosen. In this case the node will turn red until the simulation is completed but the Blender interface will remain interactive.

4.6 EnVi Nodes

4.6.1 The EnVi Geometry node

The EnVi Export node (figure 17) exports Blender scene geometry and materiality to a form more suitable for EnergyPlus analysis, which requires a very different geometry format than that typically used within Blender. The node contains one "Export" operator button. Upon pressing the "Export" button the node converts all unhidden geometry, designated as EnVi thermal or shading zones, on Blender's layer 1 and places it on layer 2 where it is coloured according to the construction type: Green for roof, grey for walls, brown for floor, turquoise for windows and red for shading geometry. The construction type is specified by applying Blender materials to faces of the geometry that have been given EnVi construction characteristics. After changes are made to the form or materiality of any geometry on layer 1 the "Export" button should be re-pressed to convert and copy the new geometry to layer 2. Layer 2 should then be checked to confirm the correct geometry and construction designation. The node has one output socket, "Geometry out" for connection to another EnVi node's "Geometry in" socket

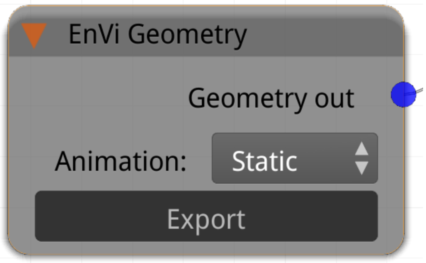


Figure 17: EnVi Geometry node

4.6.2 The EnVi Export node

The EnVi Export node converts the modified Blender geometry and materiality on layer 2 into a valid EnergyPlus text description. It combines this geometry data with the weather data specification in the connected location node and the terrain context to create a complete EnergyPlus text input file. The input file created is called in.idf and is stored in the project directory which is in the same location as the saved Blender file. It is also registered within Blender's text editor, and can be edited before eventual simulation if required.

The desired individual metrics to be simulated and available later for visualisation can also be chosen here with the check boxes at the bottom of the node. The check boxes shown are dependant on the selection in the "Results Category" drop-down menu.

The node has two input sockets: "Geometry in" for connection to an EnVi geometry node's "Geometry out" socket and "Location in" to connect to a VI location node's "Locaton out" socket, and one output socket "Context out", for connection to an "EnVi Simulation" node's "Context in" socket. The connected "VI Location" node must have "EPW" selected as its information source. If valid input socket connections are made an "Export" button will appear at the bottom of the node.

Figure 18: EnVi Export node

Specific options are:

- Name/location - provides a text box for the optional entry of an EnergyPlus project name
- Terrain - specifies the type of terrain the building sits in.
- Start/end month - specifies the beginning and end month for the simulation.
- Time steps - specifies the number of simulation time steps per hour

- Results category - chooses the class of metrics to be calculated. Options are "Zone Thermal", "Comfort", "Zone Ventilation", "Ventilation Link".
- Individual tick boxes for specific metrics within the chosen results category class.

Upon pressing this the in.idf file is created in the project directory and the "Context out" socket will become visible.

4.6.3 The EnVi Simulation node

The EnVi Simulation node (figure 19) initiates an EnergyPlus simulation. The EnVi Simulation node has two sockets: "Context in" for connection to another node's "Context out" socket, and "Results out" for connection to a "VI Chart" node or a "VI CSV Export" node. The node contains a text box into which the name of the EnergyPlus results file (default is "results") can be specified. This file, with the extension .eso, is saved in the project directory. Once a valid socket connection has been made to the "Context in" socket a "Calculate" button appears, which when pressed initiates the EnergyPlus simulation. The node will then turn red and will monitor the EnergyPlus simulation and give a prediction of simulation progress. The Blender interface should remain interactive during simulation. When the simulation is finished results can either be plotted or exported in CSV format by connecting a VI Chart node or VI CSV node to the 'Results out' socket.

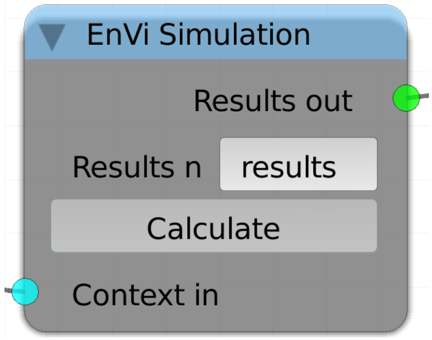


Figure 19: EnVi Simulation node

4.7 EnVi Network Nodes

EnVi Network Nodes are used within the EnVi Network node tree to specify zone schedules and natural ventilation networks. For details of the meaning of the options presented by these nodes see the EnergyPlus reference document http://nrel.github.io/EnergyPlus/InputOutputReference/01d-InputOutputReference/.

4.7.1 The EnVi Zone nodes

EnVi zone nodes are created automatically in the "EnVi Network" node tree during EnVi geometry conversion. Input sockets are created for HVAC, occupancy, equipment and infiltration specification. If a Blender object's material has the airflow surface or boundary surface option turned on sockets are also created for these surfaces. These sockets are coloured brown if representing a boundary surface, green if representing a sub-surface flow component associated with opening surfaces like windows or doors, and red for a surface flow associated non-opening surfaces such as walls, floors and roofs. These sockets are created on both sides of the node for easier arrangement of connections within the node editor.

The example in figure 20 shows a zone with two sub-surface flow faces (green sockets) associated with the zone and a one boundary face (brown socket). The node is coloured red as there are no connections to these sockets. The three flow and boundary surfaces express themselves with socket names derived from the name of the material associated with the surface, the index number of the Blender face and an "s" to denote a surface flow or "ss" to denote a sub surface flow or a "b" to denote a boundary surface. For example, en_window_4_ss denotes that Blender material en_window is associated with a face, the face has in index of 4 and it represents a sub-surface flow. The VI-Suite itself does not currently visualise face index numbers but face index visualisation can be turned on by entering 'bpy.app.debug = True' into Blender's python console window.

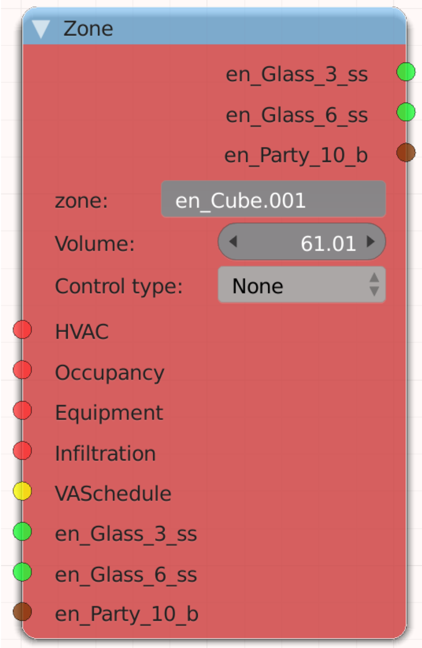


Figure 20: EnVi Zone node

Boundary sockets must be connected to another boundary socket on another zone node. Surface and sub-surface flow sockets must be connected to an EnVi Surface flow node or an EnVi Sub-surface flow node respectively. An additional input socket "VASchedule" is optional and allows the specification of a venting availability schedule for the zone.

If an airflow or boundary socket on one side of the node is connected it will disappear from the other side of the node. When all airflow/boundary sockets are either connected or hidden the node becomes valid and will turn the default colour. It should be noted that any EnVi zone must have at least two airflow surfaces specified within it, and at least two sets of flow sockets should appear in the node.

The node also displays the name of the Blender object/EnergyPlus zone, the calculated volume of the node and the ventilation control type. Control types are "None", "Constant" and "Temperature". If "Temperature" is selected a new input socket "TSPSchedule" must be connected to an EnVi schedule node. This schedule will set thermostat temperature set-points above which the zone airflow connections will all considered to be fully open. Some extra options are then also displayed:

- Minimum OF - the minimum opening factor of the ventilation flow surfaces
- Lower - the lower temperature difference threshold
- Upper - the upper temperature difference threshold

See the EnergyPlus input/output reference file for details on these options.

4.7.2 The EnVi HVAC node

The EnVi HVAC node can created from the 'Add - Zone Nodes' menu and controls the heating and cooling for the zone represented by the connected EnVi Zone node. An example of such a connection is shown in figure 21. As EnergyPlus is developed in America, where the heating and cooling of spaces with air is common, the options within the HVAC node specify the temperature, flow rates and heating/cooling capacity of the incoming air.

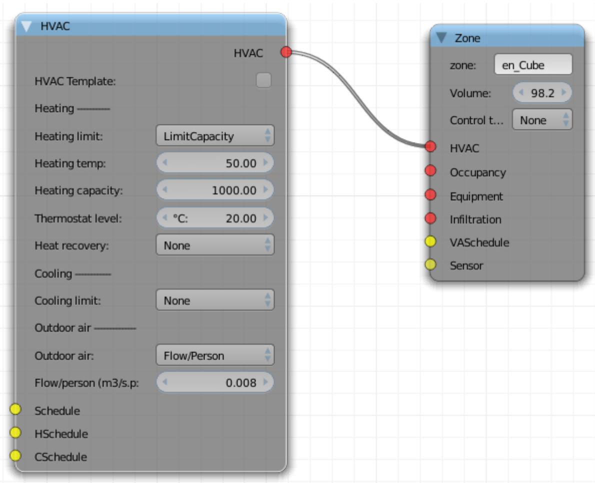


Figure 21: EnVi HVAC specification

Node options are:

- HVAC Template - whether an HVAC template should be used (as of v0.3 only an ideal load air system has been implemented)
- Heating limit - What type of heating limit is applied to the zone. Options are "None" (no heating), "No limit" (no limit to the heating capacity of the system), "LimitFlowRateandCapacity" (specify both the air flow limit and the heating capacity of the system), "LimitCapacity" (limit only the heating capacity of the system) and "LimitFlow" (only limit the heating air flow rate).
- Heating temp. - The temperature of the heating airflow
- Heating airflow - if a "Heating limit" has been set that limits air flow this maximum air flow value is set here.
- Heating capacity - if a "Heating limit" has been set that limits capacity this maximum capacity value is set here.
- Thermostat level - sets the thermostat temperature for the zone, this thermostat set-point can be scheduled by attaching a schedule (see section 5.5.6) node to the 'HSchedule' input socket.

These same options are presented for the cooling section with the thermostat cooling temperature schedule set by a schedule node connected to the 'CSchedule' node.

The Outdoor air section allows the specification of how much of the incoming heating air is drawn from outside. If 'Outdoor air' is set none the heating air is purely recirculated.

The overall scheduling of the HVAC system can be set with a schedule node attached to the 'Schedule' input socket.

The node also contains three schedule input sockets: 'Schedule' for setting the availability of the heating/-cooling system, 'HSchedule' for setting the heating thermostat schedule and 'CSchedule' for setting the cooling thermostat schedule.

4.7.3 The EnVi Occupancy node

The EnVi Occupancy node sets the level and timing of occupancy for the zone represented by the connected 'EnVi Zone' node. An example of such a connection is shown in figure 22

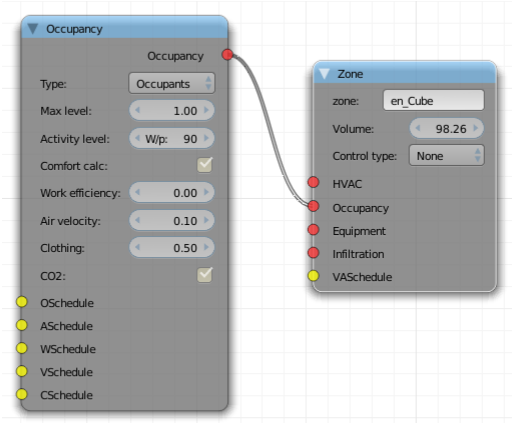


Figure 22: EnVi Occupancy specification

The occupancy node contains options for the level of occupancy, the metabolic rate, work efficiency and clothing level of the occupants and the average air velocity within the zone (all required for thermal comfort calculations) and whether to calculate air-quality via CO_2 levels within the zone.

An occupancy node has the following options:

- Type - specifies the occupancy type and the maximum value of this occupancy type to be seen by the zone.
- Max level - specifies the maximum level of the occupancy type.
- Activity level - if no activity schedule is specified then a constant level of activity is specified here.
- Comfort calc. - turns on reporting of comfort metrics (as of v0.3 PMV and PPD can be calculated)
- If Comfort calc. is selected a number of further dialogues appear to control the work efficiency, air velocity and clothing levels and turn on CO_2 monitoring.

Scheduling for most parameters in this node can be turned on by connecting a schedule node to the appropriate input schedule socket.

The node contains 5 schedule input sockets: 'OSchedule' for the specification of the occupancy schedule, 'ASchedule' for the specification of the occupant activity (metabolic rate), 'WSchedule' for the specification of the work efficiency schedule, 'VSchedule' for specification of the air velocity schedule and CSchedule for the specification of the clothing schedule.

4.7.4 The EnVi Equipment node

The EnVi Equipment node specifies the equipment level as internal heat gain for the zone represented by the connected zone node. An example of such a connection is shown in figure 23.

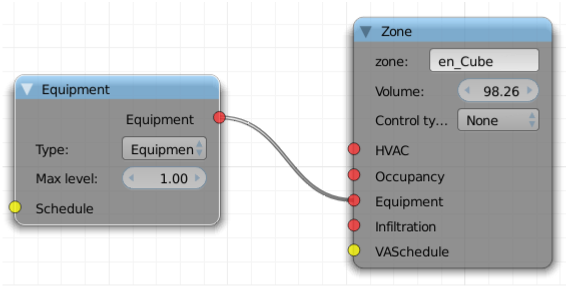


Figure 23: EnVi Equipment specification

The node sets the type and level of the internal equipment heat gain. The node has one input schedule socket for the specification of the equipment schedule.

4.7.5 The EnVi Infiltration node

If no advanced air-flow network is created then simple air infiltration for the zone represented by the connected EnVi Zone node can be specified here. An example of such a connection is shown in figure 24.

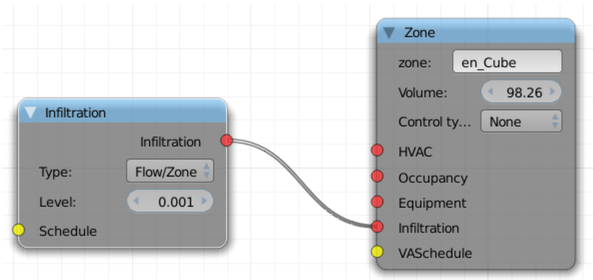


Figure 24: EnVi Infiltration specification

The node sets the infiltration type and level and contains one input schedule socket: 'Schedue' for the specification of the infiltration schedule.

4.7.6 The EnVi Control node

The EnVi control node is created automatically within the EnVi network node tree during EnVi geometry conversion if a Blender object/EnergyPlus zone contains air flow surfaces. The EnVi control node specifies the high level options for the ventilation network. For more details of these options refer to the EnergyPlus input/output reference document. An important option here is "WPC type", which if set to "Input" requires an array of wind pressure coefficients to be specified. The wind angles for these values are specified with a WPC Array node attached to the WPC Array socket of the control node. EnVi External nodes attached EnVi Surface flow and EnVi Sub-surface nodes then specify the wind pressure coefficient values for these angles for particular surfaces.

4.7.7 The EnVi WPC Array node

The WPC Array node attaches to the EnVi Control node via the Control node's "WPC Array" socket node and specifies the angles of the wind from North that wind pressure coefficient values are specified for in the "EnVi External" nodes.

4.7.8 The EnVi Schedule node

The EnVi Schedule node can be found in the "Add" - "Schedule nodes" menu in the "EnVi Network" node tree. A schedule node creates an EnergyPlus schedule, which is used to control an input's time dependence e.g when windows are open. All EnVi schedules basically operate over defined periods of a year, for defined days within that period, and defined hours of those days. The node options reflect the specification of these three layers of time data. The node is initially red and will only become the default colour when the options below are given valid values. The options are:

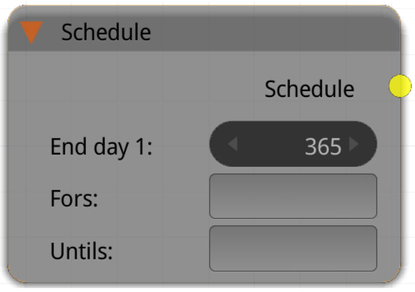


Figure 25: EnVi Surface flow node

- "End day 1" - sets the end day of the first schedule's year period. This defaults to 365, the last day of the year.
- "Fors" - sets the day types (valid day types are: Alldays, Weekdays, Weekends, Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday and AllOtherDays) for the above year period in a space separated list. *weekdays weekends* would for example set two day types for the next "Untils" option.
- "Untils" - sets the schedule values with space separated end hour/value pairs, comma separated for each period within a day type and semi-colon separated for each day type. *12:00 1, 24:00 0; 24:00 1* would, for example, mean on the first day type (weekdays) the schedule value is 1 from midnight up to midday, and 0 up to midnight, and for the second day type (weekends) the schedule value is 1 up to midnight. A whole day period must be covered so 24:00 should always be the last time specified.

If the first end day is less than 365 the three options above are repeated for the next year period. Up to four year periods can be set.

4.7.9 The EnVi Surface Flow node

The "EnVi Surface flow" node creates a flow component within a solid building construction such as a wall, floor or roof. It contains two input sockets "Node 1" and "Node 2", and two output sockets "Node 1" and "Node 2". Having sockets on both sides of the node makes node connections within the node tree more flexible but only one needs to be connected so if a node socket on one side of the node is connected, the similarly named socket on the other side of the node will disappear. All of these sockets are for connection to the surface flow sockets of "EnVi Zone" nodes.

If both "Node 1" socket and "Node 2" sockets are connected to two different EnVi zones the surface flow node is assumed to specify a flow component between the two zones. If only one socket is connected to an EnVi zone node the surface flow is assumed to sit on the external boundary of the zone and control airflow between the zone and the outside air. If "Input" is selected for the "WPC type" in the “EnVi Control” network node, an "EnVi External" node must then be connected to the other socket to represent outside conditions.

Options in this node include:

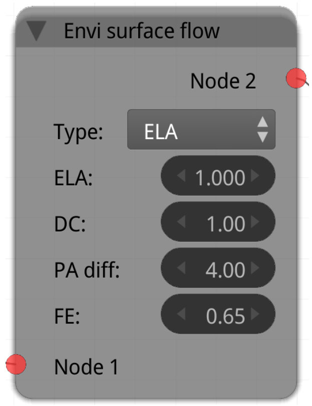


Figure 26: EnVi Surface flow node

- Type - the type of flow component (effective leakage area (ELA) or crack)
- Subsequent options control the parameters of the selected component type. Refer to the EnergyPlus input/output reference file for further details.

4.7.10 The EnVi Sub-surface Flow node

The EnVi Sub-surface Flow node creates a flow component within an opening building construction such as a window or door. It contains two input sockets "Node 1" and "Node 2", and two output sockets "Node 1" and "Node 2". All of these sockets are for connection to the sub-surface flow sockets of EnVi Zone nodes. If a node socket on one side of the node is connected the similarly named socket on the other side of the node will disappear. This makes node connections within the node tree more flexible. If both "Node 1" socket and "Node 2" socket are connected to two EnVi zones the subsurface flow is assumed to control airflow between the two zones. If only one socket is connected to an EnVi zone node the surface flow is assumed to sit on the external boundary of the zone and control airflow between inside and outside.

An additional socket is the "VASchedule" input socket which allows for the specification of a venting availability schedule for the component.

If the "Control type" option is set to "Temperature" an extra socket is created to allow a thermostat schedule to be specified.

Options in this node include:

- Type - the type of flow component (simple opening, detailed opening, horizontal opening, effective leakage area or crack)
- Subsequent options control the parameters of the selected component type. Refer to the EnergyPlus input/output reference file for further details.

Figure 27: EnVi Sub-surface flow node

4.7.11 The EnVi External node

The EnVi External node provides wind pressure coefficients for the outside surfaces of the building. These nodes are only required if the "WPC type" option in the EnVi control node is set to "Input". The node has sub-surface flow and a surface flow sockets as both inputs and outputs. Joining these sockets to a flow component specifies the building wind pressure coefficients for the angles specified by a WPC Array node. A WPC Array is therefore required to be connected to the EnVi control node for these nodes to be valid.

4.7.12 The EnVi Reference Crack Conditions node

This optional node sets the reference temperature, pressure and humidity for any ventilation cracks specified within the network. If not created, EnVi will assume standard values for these parameters, which are the same as the default values presented within the node.

5 Using the VI-Suite

5.1 Sun Path Projection

Projecting a sun-path analysis into the Blender scene requires a VI Location node to be created to provide the latitude and longitude co-ordinates of the scene. The VI Location node can either take the latitude and longitude values from an EPW file, or they can be entered manually. The start and end month options of the location node are not exposed when doing a sun path analysis as a whole year is always considered. Once the location node has been set-up a Sun Path node can be created and the "Location out" socket of the location node dragged to the "Location in" socket of the Sun Path node. A typical node set-up is shown in figure 28.

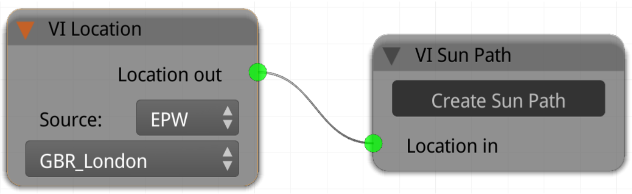


Figure 28: Sun Path node set-up

The Sun Path node itself has no options, only a button to be clicked to create the sun-path. Along with a sun-path mesh, a sun lamp and spherical mesh to represent the sun and a sphere is created to represent the sky. The sun-path has 4 materials associated with, and the colour of each of these materials can be changed as desired or made transparent.

Once a sun-path has been created a number of options are presented with the 3D view properties panel in the "VI-Suite Display" tab (section 4.2). The sun path options display options available are shown in figure 29. The first and second options control the day of year and time of day for the position of the sun lamp and the sun mesh, the third option controls the scale, or size, of the sun-path (any scaling done within the 3D view will reset upon changing the position of the sun with the first two options). The fourth option controls the display of the hour numbers on the sun-path. If the "Display hours" option is selected then the last options control the representation of the hour numbers: font size, font colour and font shadow colour. The sun path mesh can be moved around the scene and the sun will follow when the time of day/year is updated. Day of year and time of day can be animated within Blender and the sun will move accordingly.

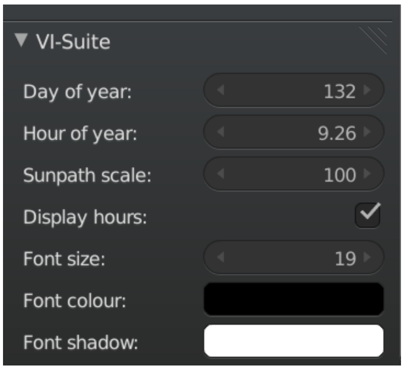


Figure 29: Sun Path visualisation options

If using the Cycles rendering engine a couple more capabilities are enabled. If the Hosek/Wilkie sky is selected as the sky texture in the world background settings the sun orientation within the sky texture will update to correspond to the sun-path sun position. In addition, if the sun and sun mesh are given an emissive material, with a black-body temperature colour, the black-body colour will also change according to the position of the sun in the sky; orange/red near the horizon, white near noon.

As the sky background is much further away from the 3D viewpoint than the sun and the sun path mesh, then if the viewpoint is not near the centre of the sun path mesh there will be a misalignment between the sun and the brightness of the sky background. To rectify this a "SkyMesh" is also created, but is hidden by default. This sky mesh is a sphere, the surface of which sits just outside sun path mesh. If in "Cycles" rendering mode unhide the sky mesh and select "Emission" as the surface for the "SkyMesh" material, select "Sky Texture" for colour and select "Texture Coordinate - Normal" for the vector setting. When the 3D viewpoint is now inside this sky mesh sphere, the sky texture will be projected onto the inside of the sphere in accordance with the sun position, and will line up more closely with the sun-path mesh itself.

5.2 Wind Rose Creation

Projecting a wind rose into the scene also requires a VI Location node. In this case however the location node provides wind speed and direction data for the wind rose analysis and therefore an EPW file must be chosen as the source of information within the location node. A typical node set-up is shown in figure 30.

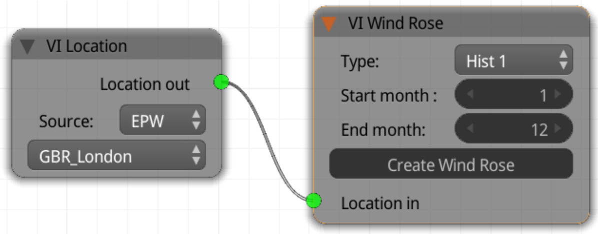


Figure 30: Wind Rose node set-up

The options within the wind rose node control the type of wind rose plot to create, and the start and end months of the date range to plot. Two types of histogram and three types of contour plot are available. Examples of a histogram and contour plot are shown in figure 31.

Once the button to create a wind rose is pressed a wind rose object is created at the centre of the scene. This object, like any Blender object, can be moved, scaled and re-sized as desired. Each time the wind rose button is pressed a new object is created.

When a wind rose object has been created one option will be exposed in the "VI-Suite Display" tab (section 4.2) of the 3D view properties panel; "Legend". This turns on the legend in the top left of the 3D view that relates wind rose colour to wind speed. This legend will apply to the last wind rose object created.

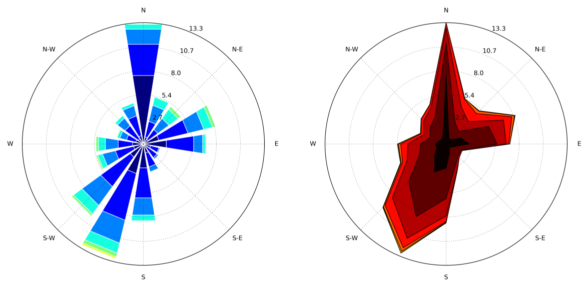


Figure 31: Histogram and contour wind roses

5.3 Shadow Study

The shadow study node also requires a VI Location node to provide latitude and longitude co-ordinates so either an EPW file or manual entry can supply this data. A typical node set-up is shown in figure 32.

A shadow study analysis requires sensing geometry to be specified. This geometry is specified via its material designation. Once a Blender object has a material associated with it (and this material can only be associated with specific faces of an object if desired) then in the Blender material panel in "Vi-Suite Material" tab there is an drop-down menu called "Material type". Within this menu the option "Shadow sensor" should be selected. An analysis will then plot on this sensing geometry a grey-scale colouration signifying how often that point receives direct sunlight, when the sun is above the horizon, for the specified simulation period.

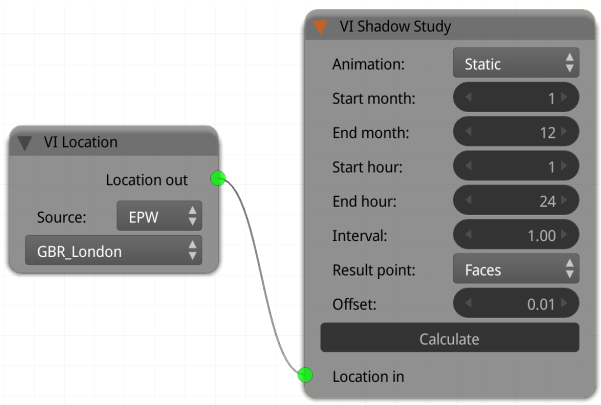


Figure 32: Shadow Study node set-up

The year period for the simulation is set within the Shadow Study node with the start month and end month options. The period of each day to be simulated is set with the start hour and end hour options. The "Interval" option sets the hourly time step for the simulation. A value of 1 will do a calculation once per hour, and a value of 0.25 will do one every 15 minutes. The "Animation" option allows either a static analysis or one based on a geometry animation. If "Static" is selected then results are valid for the current selected frame. If "Animated" is selected results will be generated for each frame of the created animation.

In the 3D properties panel (section 4.2) the "VI-Suite Display" tab will present a shadow study display button and once this is pressed will also show options relevant to the shadow study. The display panel options are shown in figure 33.

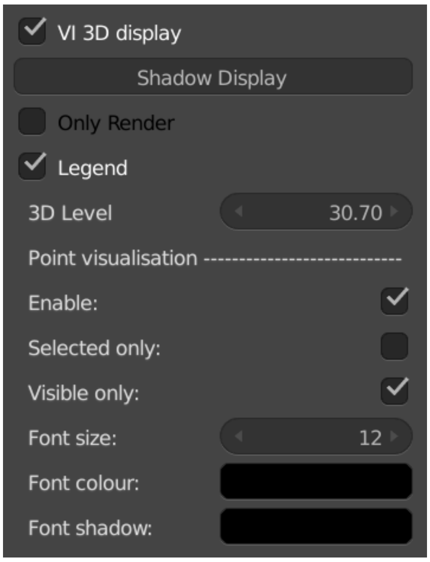


Figure 33: Shadow study display options

The options in the display panel are:

- VI 3D Display - If selected before the display button is pressed the results can be extruded to provide 3D result visualisation.
- Shadow Display button - When clicked will initiate display and expose further display options.
- Only Render - Removes some interface elements from the 3D view
- Legend - Turns on the legend display in the top left of the 3D view
- 3D Level - If VI 3D Display was selected this number will extrude the results plane for 3D results visualisation.

In the Point Visualisation section:

- Enable - Turns on per-point numerical visualisation of the results
- Selected only - Only the currently selected object will display numerical results
- Visible only - Only points not obscured in the 3D view show numerical results
- Font size, font colour, font shadow - changes the colour and size of the point numerics.

Figure 34 shows a shadow study analysis of the terrain around Mount Snowdon.

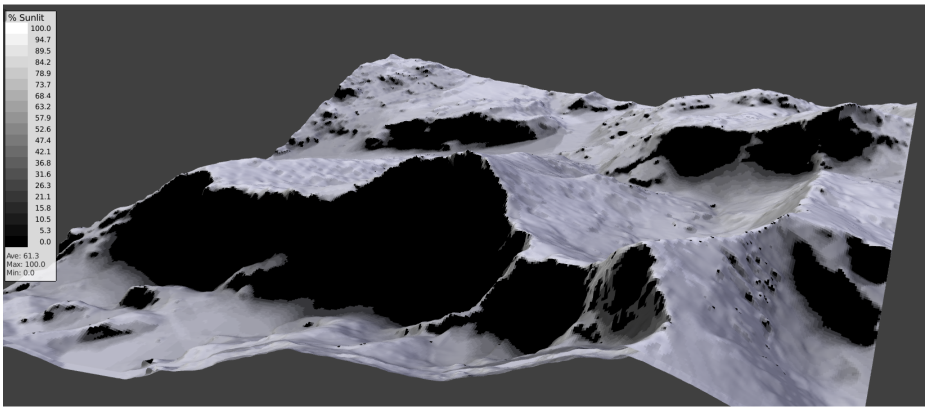


Figure 34: Shadow study analysis of Mount Snowdon

5.4 LiVi Lighting Analysis

Lighting analysis is conducted with the LiVi component of the VI-Suite, which acts as a pre/post processor for the Radiance software simulation suite. A valid Radiance installation is therefore required on the host machine unless the pre-packaged zip files are used which contains the required Radiance files. Details of the installation process can be found in section 2.

There are five main LiVi nodes: LiVi Geometry, LiVi Context and LiVi Simulation. All are detailed in section 4.5. A LiVi analysis will require a LiVi Geometry node, LiVi Context, and a LiVi Simulation node.

A numerical LiVi lighting analysis, like a shadow study, requires geometry within the scene to be identified as sensing geometry. This is done in the material panel within the "Vi-Suite Material" section where the option "LiVi Sensor" should be selected in the "Material type" drop-down list. All geometry to which this material is associated will now act as a sensing plane. Exceptions to this requirement is if a glare study, or only a preview of the Radiance scene, is to be conducted. The sensing geometry senses in the direction of the Blender sensing face or vertex normals.

5.4.1 LiVi Geometry

The LiVi Geometry node, which can be found in the "Add" - "Export Nodes" menu of the VI-Suite node editor, controls the export of the of the Blender scene geometry and materiality to the Radiance text file format. Only geometry on the current Blender layer is exported meaning that a number of different scene scenarios can be set up on different Blender layers. Within a layer, any geometry that is not hidden, and has at least one material associated with it, will be exported.

Upon pressing the node's "Export" button the node first converts Blender materials to Radiance material descriptions. Specification of the Radiance material type for a particular Blender material is done within Blender's material panel. At the bottom of the material panel a section called "VI Material Type" presents a drop down menu called "LiVi Radiance type" that allows the designation of the Radiance material type for the selected Blender material. Options include "Plastic", "Metal", Glass" etc. Options to further specify the Radiance material are then presented.

Next, suitable geometry is exported as obj files to the "obj" folder created in the project directory. The obj files are then automatically converted to Radiance mesh files, with Radiance's obj2mesh program, and referenced within the Radiance input text. Actual object vertex co-ordinates are instead written out to the Radiance input if a Blender object's geometry is non-manifold i.e. not physically realisable (e.g. an edge without faces), or if a "Mirror" or an "Emission" material is associated with an object as Radiance meshes cannot have these material attached.

Next Blender lights are exported to Radiance format. There are two ways to set-up lights for Radiance export: Creating standard Blender lamps, or creating a plane at each face of which a lamp is automatically specified. If using the first method then selecting a lamp within Blender will display a "LiVi IES File" section at the bottom of the Lamp properties panel. In this section it is possible to specify an IES file to associate with the Blender lamp. IES files are released by luminaire and lamp manufacturers, and describe the brightness of a luminaire or lamp from multiple directions. The desired IES can be picked with the "Select IES File" button. Three additional options are also presented:

- IES Dimension - specifies the distance unit for the geometry described in the file
- IES Strength - which allows the light to be dimmed (can be animated)
- IES Colour - sets the colour of the lamp (can also be animated).

The second method allows any selected mesh object to have an IES file associated with it via the "LiVi IES file" section of the "Object data" panel. Any IES file selected here will now be applied in the Radiance scene at each face centre of the mesh object. This is useful for quickly setting up arrays of lights.

Radiance material, geometry and light descriptions are finally written as text and stored within the node.

If an object with a "LiVi sensor" material is exported the sensing point co-ordinates are written to the *blender_filename*.rtrace file, and saved in the project directory.

If undertaking an animated analysis LiVi will export a Radiance scene for each frame from Blender's start frame to end frame. The range of frames considered for analysis can be set within the node if the 'Animated'

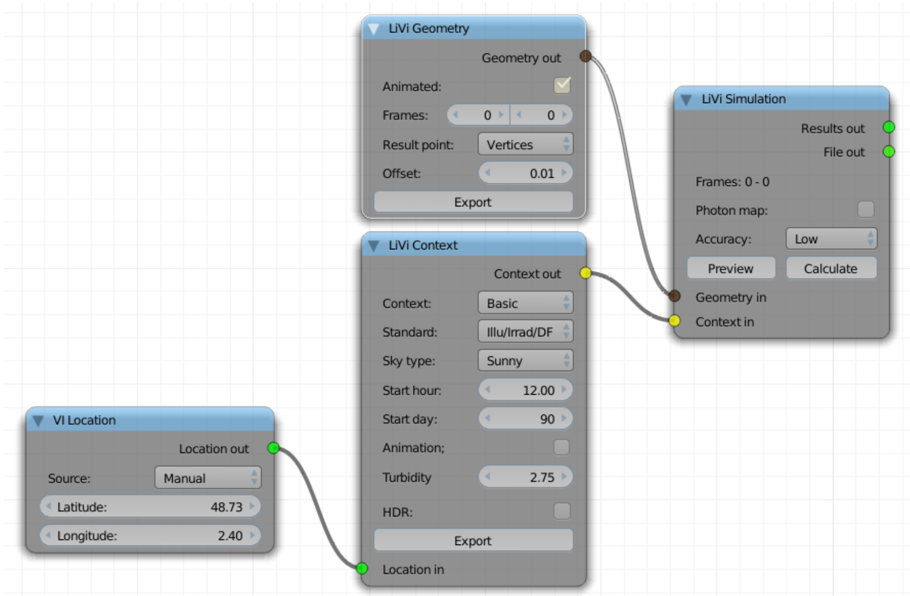


Figure 35: Typical LiVi node set-up

option is selected. Any animation of geometry, material or lighting set up within Blender for the selected frame range will be simulated.

5.4.2 LiVi Context creation

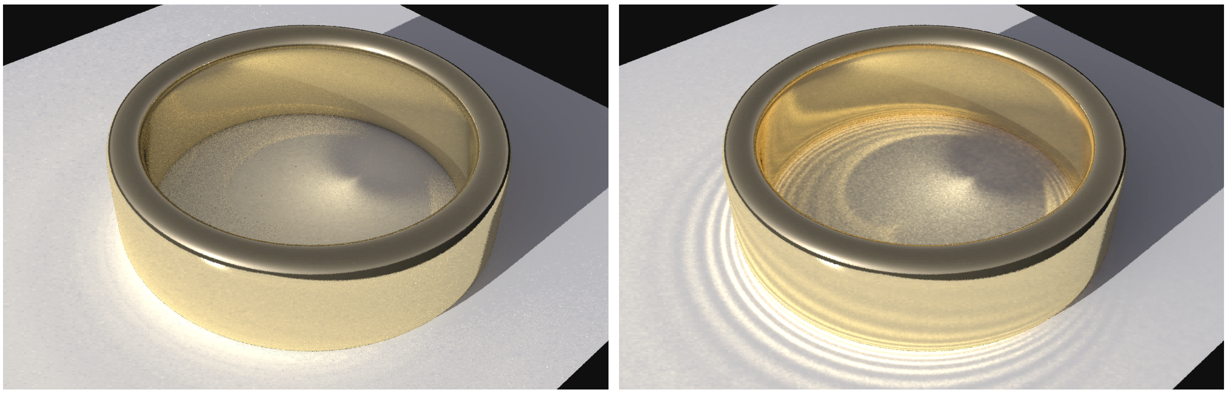
A basic analysis allows for the prediction of illuminance (lux), irradiance (W/m^2), Daylight Factor (%) and glare. The first three metrics are plotted onto sensing planes, in a similar manner to the shadow study analysis, using the "rtrace" component of Radiance. A typical node set-up is shown in figure 35.

A lighting compliance analysis can be selected from the 'Context' menu of the LiVi Context node. A LiVi compliance analysis checks lighting performance against internationally recognised standards. As of VI-Suite version 0.3 compliance with BREEAM HEA1 and Code for Sustainable Homes can be assessed. Once a LiVi compliance context has been exported a compliance specific drop-down menu is exposed within the "VI-Suite Material" tab of the material panel to define the type of space a particular sensing material is associated with. For a BREEAM residential property, for example, this option can select a Kitchen, Living/Dining or Communal space.

A Climate Based Daylight Modelling (CBDM) analysis can be selected from the 'Context' menu in the LiVi Context node and allows the lighting performance of a building over longer periods of time to be analysed. The information for the environmental lighting conditions is provided (at least initially) by a location node, taking an EPW file as its source of information.

5.4.3 LiVi Simulation

A complete node set-up for a LiVi simulation is shown in figure 35. The simulation node initiates either a visualisation preview of the Radiance model, from the point of view of the Blender camera, with the 'Preview' button or the Radiance simulation with the 'Calculate' button. Once the Calculate button is pressed the Radiance simulation is initialised, and when finished (the Blender interface will lock up while the simulation runs unless a glare analysis has been selected), display options appear in the VI Display section of the 3D view properties panel. These display options are detailed in section 5.4.5. When completed the Radiance results are stored within the meshes of the sensing geometry for visualisation. Options in the "VI Display" panel detailed in section 5.4.5 control visualisation of these results unless a glare analysis has been selected. Glare analysis has a different visualisation process also detailed in section 5.4.5.



(a) Without Photon Mapping (b) With Photon Mapping (500,000 global photons and 5,000,000 caustic photons)

Figure 36: One Photon map to rule them all

5.4.4 Photon Mapping

Photon mapping capabilities have been included in version 5.0 of Radiance. Photon mapping can produce more accurate and quicker results in situations where light sources are to hard to find from the point of view of the LiVi sensor points e.g. light to the sensors is delivered through light redirecting devices, and when there are specular surfaces that result in caustics. A classic caustics context is the characteristic pattern at the centre of a obliquely illuminated reflective ring (figure 36).

Within the Blender interface there is one option relevant to using Photon mapping which is situated in Blender's material panel in the 'VI-Suite Material' tab. This option turns on Photon Port status for that material. As the Photon Mapping pre-pass sends out rays from the light sources it is useful in some cases to turn on photon ports to guide these rays to the relevant geometry. When, for example, doing a lighting analysis for the interior of a building setting up the Photon Port material for the windows on the building periphery will guide the lighting from the sky to the building interior, vastly reducing up time it takes for the relevant scene geometry to receive the number of photons required. The normal of the surface with the Photon Port material attached should point into the room in this case.

The node options relevant to Photon Mapping reside within the LiVi Simulation node. Here Photon Mapping can be activated, and the number of global (diffusely reflected), and caustic (specularly reflected) Photons can be set. In the example shown in figure 36 global photons were set to 500,000 and the caustic photons set to 5,000,000. If previewing the scene with 'Preview' button the rvu window will not appear until the required number of photons have interacted with the relevant geometry.

5.4.5 LiVi Display

Apart for a LiVi Basic glare analysis LiVi display options are presented within the “VI Display” section of the 3D View’s properties panel (toggled with the "n" key over the 3D display). A basic ’VI Display’ section is shown in figure 37.

Initially only the "VI 3D display" toggle and the "Radiance Display" button are shown. The "VI 3D display" toggle controls whether a 3D display of the results metric is desired. Once the "Radiance Display" button is pressed new Blender objects will be created coloured according to the Radiance results and further options are presented. These options include:

- Only Render - toggles the display of the 3D cursor, axis, wire-frames and object manipulators
- Legend - toggles the display of the legend
- Legend max/min - specifies the the maximum and minimum value for the legend and colour display (placing the mouse cursor over the top or bottom of the legend in the 3D display and scrolling with the mouse wheel will also alter the legend max/min values)
- Legend scale - switches result colouration and 3D result extrusion between lineal and log (log is useful when there is a large difference between the maximum and minimum results for example when the sun is shining directly on part of the sensing surface).
- Draw wire - toggles the display of a wire-frame for the selected object. May need to be selected twice to turn on the wire-frame.
- 3D Level (only appears if VI 3D display option was chosen) - controls the level of 3D extrusion of the results geometry
- Transparency - set the transparency level of the result geometry

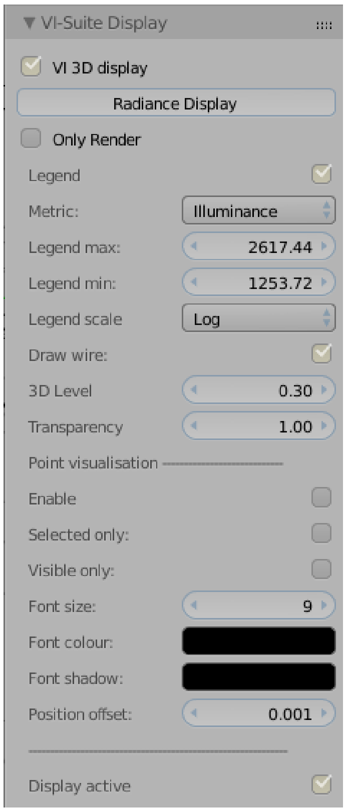


Figure 37: "VI Display" options

The next section controls the display of numerical result values for each point of the sensing geometry. Options in this section include:

- Enable - toggles numeric display
- Selected only - display numerical results only on the selected geometry
- Visible only - only the sensing geometry points visible within the 3D view display numerical values (orientating the view to the selected object may be required to correctly calculate which points are visible)
- Font size, colour, shadow controls the number display
- Position offset - controls the offset point for the numerical display (in general should be set to the same value as the offset value in the "LiVi Geometry" node).

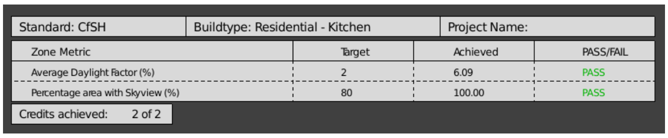
The "Display active" option at the bottom turns off result display. This should be used when results display is no longer required as using Blender’s undo feature can crash Blender if this is left on.

If a compliance analysis was undertaken and extra section is presented (figure 38) to control the compliance panel display.

In this section the first option is to turn on the compliance panel, and the next 4 options allow the user to enter text strings with project specific information: Assessing organisation, Assessing individual, Job number and Project name. Enabling the compliance panel will show a table at the top left of the 3D view that displays the relevant metric benchmarks to be achieved, the actual value achieved, whether this constitutes a pass or fail, and the number of credits achieved. The total number of credits achieved box assumes that all spaces in a project that need to show compliance have been modelled and simulated. If only a subset of spaces has been simulated this number will not reflect the credits gained for the whole building. At the bottom of the 3D view another table will appear with assessing organisation, assessing individual, and job number displayed, for the production of reports.

Figure 38: Additional LiVi Compliance display options

Bear in mind that the VI-Suite is released as free and open-source code and comes with no warranty. If using the compliance analysis for consultancy work it is the responsibility of the user to ensure that the results are valid.



Standard: CfSH	Buildtype: Residential - Kitchen	Project Name:	
Zone Metric	Target	Achieved	PASS/FAIL
Average Daylight Factor (%)	2	6.09	PASS
Percentage area with Skyview (%)	80	100.00	PASS
Credits achieved: 2 of 2			

Figure 39: LiVi Compliance panel

Glare analysis differs from other LiVi analyses in that once the "Calculation" button of the simulation node is pressed, no visualisation options appear in the VI Display Panel. Instead grey-scale fish-eye images, from the point of view of the Blender camera are created, with coloured areas showing glare risk. These images are saved in the project directory with the name glare-*frame_number*.hdr, and also registered within Blender's image database; and can therefore be viewed by opening up a Blender UV/Image editor window. LiVi also writes out the glare metrics calculated from the image on the right hand side of the image, along with the data and time specified in the LiVi Basic node.

5.5 EnVi Energy Analysis

The EnVi component of the VI-Suite is a pre/post processor for the EnergyPlus simulation engine (http://apps1.eere.energy.gov/b An EnVi analysis requires a "VI Location" node to provide an EnergyPlus weather file for the simulation, an EnVi Geometry node to pre-process the full Blender geometry into the sub-set of the geometry that will be used in the EnergyPlus simulation, an EnVi Export node to convert the sub-set of the Blender geometry and the building context to the EnergyPlus text format, and finally an EnVi Simulation node to run the simulation. Optionally, a VI-Suite chart node can be used to plot out the simulation results. A typical node layout is shown in figure 40.

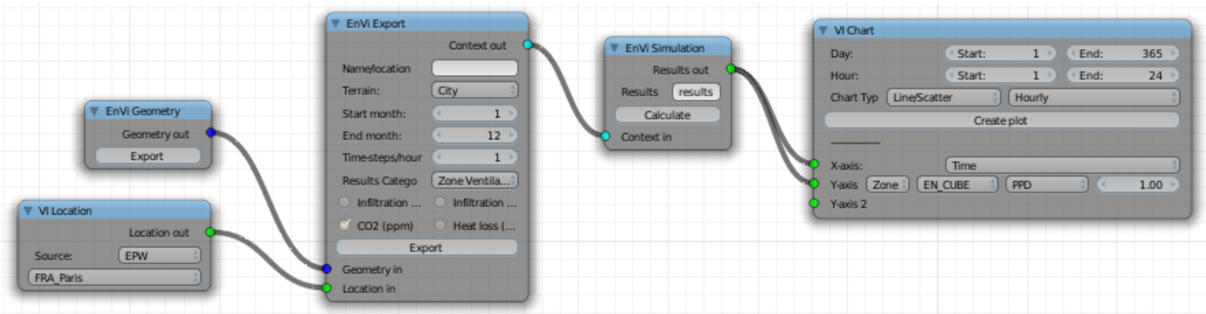


Figure 40: Typical EnVi node set-up

5.5.1 EnVi construction specification

EnergyPlus, like many whole-house energy modelling systems, only requires geometry comprising of simple planes with construction attributes then associated with them. These construction attributes are created in Blender using Blender's materials system. Within Blender's Material properties panel is a section called VI-Suite Material and within this section is the 'EnVi Construction Type' drop down menu. In this menu the basic type of EnVi construction can be specified:

- Wall - Typical external and party wall constructions
- Window - Typical glazing constructions
- Floor - Typical ground and upper storey floor constructions
- Roof - Typical roof constructions
- Door - External and internal door constructions
- Shading - External shading surfaces
- None - No EnVi construction type

Once a type has been selected options will appear below to choose a pre-stored construction, or to define a construction by the specification of the construction's layers. Pre-defined construction choices are currently quite limited, but new ones can be added (as detailed in section 5.5.3), and any custom material or construction created will be remembered within the Blender file. Custom materials require the input of all the material characteristics.

There can be up to 5 layers in a construction. Each layer has a thickness and characteristics such as density and thermal conductivity. It is because of these properties that EnergyPlus only needs planar geometry to be able to describe a complete building.

Each Blender material, and its associated EnVi construction designation, can be applied to individual faces of Blender objects. If the Blender object geometry is complex the materials should only be applied to the interior surfaces of the zone.

There are three more toggle options within the EnVi material panel: "Intrazone boundary", "Airflow surface" and "Thermal mass". The first tell EnVi that a surface shares a boundary with another zone. This might be a party or internal wall, or a ceiling/floor combination. The second tells EnVi that the surface is a point at which air can enter or leave the space. The last can be used for surfaces in the zone that do not transfer heat but do provide thermal mass that moderates the temperature of the zone. The first two options become important for the EnVi network creation stage, detailed in section 5.5.5.

5.5.2 EnVi geometry conversion

Once a Blender object, which has been designated as an EnVi thermal zone or shading construction, has been fully defined, and materials applied where appropriate the geometry can be stripped down to only that geometry required by EnergyPlus for simulation. EnergyPlus, like many whole-house energy modelling systems, only require geometry comprising of simple planes with construction attributes then associated with them. An EnVi Geometry conversion is first required to turn complex Blender geometry into simplified geometry suitable for energy analysis. During the conversion process Blender geometry on Blender layer 1 is converted to simplified Blender geometry on layer 2. Only the geometry specified as an EnVi zone and object faces with an EnVi construction material assigned are converted.

Every export will overwrite the geometry on layer 2, so it is important that any changes to form or materiality are made to layer 1 geometry and the EnVi geometry re-converted with the EnVi Geometry node.

Upon export, objects with an EnVi property, and faces with an EnVi material, are exported to Layer 2. Faces are coloured according to the construction type: walls are white, floors are brown, roofs are green, windows are turquoise and shading surfaces are red.

5.5.3 Storing EnVi custom constructions

Within the VI-Suite scripts directory is a file called envi_mat.py, that contains all the built-in material and construction specifications accessible by EnVi. Before changing this file it is a good idea to make a back-up copy. At the beginning of the file is a class called "envi_materials" which contains lists of material specifications in different material categories (metal, brick, cladding, concrete, wood, stone, gas (opaque construction cavity), wgas (window construction cavity), glass, insulation). If adding a material that falls under the metal category the self.metal_datd should, for example, be edited. Each list is encompassed with curly brackets, and contains a comma separated set of material specifications. A material specification within the metal list may look like

```
"Lead": ("Smooth", "35.3", "11340", "128.00", "0.05", "0.05", "0.05", "5")
```

The first word is the name of the material, the first word within brackets is the surface roughness (possible entries are: VeryRough, Rough, MediumRough, MediumSmooth, Smooth, and VerySmooth) and the following numbers are thermal conductivity (W/m-K), density (kg/m^3), specific heat (J/kg-K), thermal absorption, solar absorption, visible absorption, default thickness (mm).

A material in the glass category may look like

```
"Clear 6mm": ("Glazing", "SpectralAverage", "", "0.006", "0.775", "0.071", "0.071",
    "0.881", "0.080", "0.080", "0.0", "0.84", "0.84", "0.9")
```

Only the numbers within the brackets generally need to be changed and they represent: default thickness (m), solar transmittance at normal incidence, front side solar reflectance at normal incidence, back side solar reflectance at normal incidence, visible transmittance at normal incidence, front side visible reflectance at normal incidence, back side visible reflectance at normal incidence, IR transmittance at normal incidence, front side IR hemispherical emissivity, back side IR hemispherical emissivity and thermal conductivity (W/m-K).

In the class 'envi_constructions' additional preset multi-layer constructions can be specified.

5.5.4 EnVi zone specification

An object in Blender, in terms of EnergyPlus, can either represent nothing, a thermal zone or shading geometry. This selection is made in "Object Data" panel within the "EnVi Zone Definition" tab. If thermal is chosen, and the object has EnVi construction materials applied, then upon EnVi geometry export zone nodes are created within the 'EnVi Network' node tree. An example of an EnVi zone node is shown in figure 20. To this node can be connected HVAC, Occupancy, Equipment and Infiltration nodes to specify the characteristics of the zone.

All of these zone specification nodes can be found in the 'Add' - 'Zone nodes' menu at the bottom of the node editor.

5.5.5 EnVi network creation

EnVi network creation allows connections between zones; airflow and physical, to be defined. A physical connection would for example represent a boundary wall or floor/ceiling between two zones that heat can flow across. Air flow boundaries allow air to flow between zones or between zones and the outside. For any EnVi zone faces that have a material with the "On boundary" or "Airflow surface" property the zone node created in the EnVi Network tree will contain sockets auto-generated to represent the airflow or boundary faces within the zone. It is then simply a case of connecting the sockets between nodes to represent ventilation or physical boundaries between spaces. For example, if a face within a Blender object has a Blender material associated with it, and the "Airflow surface" option has been turned on for this material, sockets will appear within the created zone node for these airflow surfaces. If the material associated with this face is a window or door, green sub-surface sockets are created for connection to a sub-surface flow node. If the material associated with this face is a wall, floor or ceiling, red surface sockets are created for connection to a surface flow node.

5.5.6 EnVi schedule specification

The node to specify a schedule in EnVi consists of the following options. An "End day" dialog which takes a number from 1 to 365, a "Fors" dialog which takes text, and an "Untils" dialogue which also takes text. The dialogues along with sample entries are shown in figure 41.

The first dialog sets the end day of the year that each sub-schedule applies to (the start day is assumed to be the first day of the year). The second sets the types of day that the schedule applies to with a space separated list of consisting of any of AllDays, Weekdays, Weekends, Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday, AllOtherDays. Day types should not overlap e.g. placing "Weekdays "Tuesday" in the text box will cause an error as any Tuesday would be valid for both schedule days. The final box contains the semi-colon separated hour ranges for each day type of the sub-schedule. In the example in figure 41 up to day 90 of the year for all days the schedule is 0 from midnight (always the automatic schedule starting time) up to 8 in the morning, 1 until 6 in the afternoon, and 0 again up to midnight. For day 90 to 365 on weekdays the schedule is 1 all day, and on weekends the schedule is 0 up to 8 in the morning and 1 up to midnight. Each time value pair is separated by a comma.

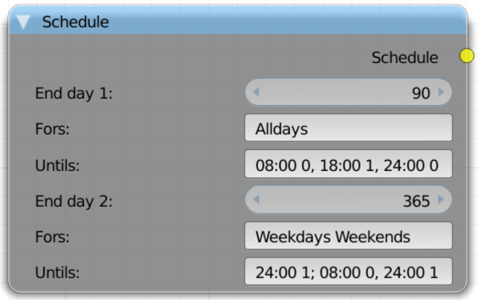


Figure 41: EnVi schedule dialogues

6 Known issues

- Only line/scatter graphs can be plotted from the VI Chart node.
- Animated EnVi analysis is not currently possible.
- Upon opening a Blender file which already has a connected VI Chart node in the node editor, a connection has to be redrawn to re-initialise the node sockets.
- When conducting a sun path study after an animated LiVi analysis that uses an animated Hosek/Wilkie sky background the animation key frames have to be removed manually from the sky background.
- Saving a png file from the matplotlib window on Windows will cause Blender to crash.
- Changing the legend scale type with point visualisation turned on can take a very long time for dense sensor meshes.

7 Acknowledgements

- Thanks go to the Blender Foundation for the creation, distribution and constant improvement of Blender.
- Thanks go to the National Renewable Energy Laboratory for the multi-platform compilation and distribution of the Radiance binaries.
- Thanks also go to National Renewable Energy Laboratory for the creation and distribution of the EnergyPlus software.
- Thanks go to the Matplotlib Development Team for Matpltlib - Copyright (c) 2012-2013 Matplotlib Development Team; All Rights Reserved
- Thanks to Continuum Analytics for producing Anaconda, which provides certain Python components for OS X and Windows platforms.
- This product includes Radiance software (http://radsite.lbl.gov/) developed by the Lawrence Berkeley National Laboratory (http://www.lbl.gov/)
- Thanks to Tony Graham for his feedback on this manual.

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