DAYLIGHT VISUALIZER AND ENERGY & INDOOR CLIMATE VISUALIZER, A SUITE OF SIMULATION TOOLS FOR RESIDENTIAL BUILDINGS

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ABSTRACT

The use of complex building simulation tools is less common in the design of residential buildings than it is for commercial buildings. In most cases, evaluations are only performed using mandatory compliance tools due to the limited time and expertise that the professionals responsible for the project have available.

Tools that allow quick evaluations of residential buildings with regards to indoor environmental quality exist, but these rarely use the dynamic simulations necessary for evaluating the performance of natural ventilation and solar shading in free-running buildings, and rarely offer the possibility to visualize the appearance of daylight in the room.

Daylight Visualizer and Energy and Indoor Climate Visualizer are free simulation tools with a simple and intuitive user interface permitting quick evaluation of residential buildings.

INTRODUCTION

The focus on tools for energy simulation and building performance evaluation remains high with the recast of the EPBD and the increasing requirements for energy performance. At the same time, there is an increasing attention put on the performance of the Indoor Environmental Quality, which increases the relevance of tools that evaluate both energy and IEQ performance.

National compliance tools focus on energy performance and generally do not offer possibilities for in-depth analyses of thermal comfort, indoor air quality and daylight conditions, particularly with regards to the effects of windows, natural ventilation and solar shading. Recent reports investigating overheating in new single-family houses indicate that increased use of IEQ analyses in the design stage could have improved thermal conditions (Larsen and Jensen, 2011; Isaksson and Karlsson, 2006).

The purpose of Daylight Visualizer and Energy and Indoor Climate Visualizer is to provide accurate and accessible simulation tools for the evaluation of IEQ in single-family houses.

An important goal in the development of the tools was to include the effects of solar shading and window opening on thermal comfort, as well as CO_2-controlled mechanical or natural ventilation for maintaining a specified IAQ.

Similar results could be obtained with the use of IES VE, TAS, IDA ICE, Radiance (Rogers, 2007; Crawley, 2008), and other complex simulation tools. The goal of Daylight and EIC Visualizer is to make performance-based evaluations available to users with limited experience, and to speed up the simulation process in order to make them economically viable in single-family projects where only limited consultancy fees are available.

USER INTERFACE

The user interface design can significantly influence the accessiblity of computer programs and can be used to simplify the simulation process found in more complex tools, which sometimes have no user interface at all.

The Daylight and EIC Visualizer user interfaces are designed to provide user guidance throughout the simulation process, to reduce the amount of simulation parameters and their complexities, and to automate complex actions through simple familiar inputs with the mouse, e.g. preparation of 3D models.

User guidance throughout the simulation process is provided via progress bars which are divided in specific steps following the process of daylighting simulation and thermal simulation. In addition, the Daylight Visualzier user interface has a specific area with simple text instruction guiding the user every step of the way.

The Daylight Visualizer simulation settings are specified via a single rendering parameter which is mapped to several internal settings determining the quality and accuracy of the simulation. All EIC Visualizer simulation settings are predefined, with no need for user interaction.

3D MODEL

Simulation results and accuracy can be greatly affected by the quality of 3D models, and they can act as a barrier limiting the use of simulation tools for users without the necessary skills or time.

Daylight and EIC Visualizer have easy-to-use 3D modellers that permit to model a wide range of room types in a few minutes. The advantage of the embedded 3D modellers is that they ensure the validity of the simulation models, and allow for quick changes in the design to succequently evaluate different scenarios. The modellers include databases of real-world window products, which can be inserted in the model by simply dragging them at a desired location over the roof or the walls. These automated modelling function help to considerably speed up the evaluation process.

Models created in Daylight Visualizer can be exported to EIC Visualizer to limit the need for creating multiple models. When exported, the geometry of models from Daylight Visualizer is automatically optimized for use in the EIC Visualizer thermal simulation, and do not require further modifications from the users. Some parameters, e.g. the properties of the thermal zone, are pre-defined with the purpose of reducing the potential mistakes made in the set-up of a simulation model.

The tools also allow users to import 3D models from other CAD programs in the following formats: DWG, DXF, OBJ, 3DS and SKP. Imported models allow the use of complex forms and permit the evaluation of very specific project design, but their geometry cannot be modified within the tools. To import 3D models in EIC Visualizer, the Pro version of the tool is required.

The tools also include lists of predefined surfaces and constuction elements to promote the use of realistic simulation inputs in the daylight and thermal calculations.

METHODS

Daylight Visualizer

Simulations in Daylight Visualizer are performed using bidirectional Monte Carlo ray tracing with photon mapping. This is a biased two pass method for simulating global illumination. In the first pass, photons are traced from light sources and the resulting hit points on non-specular surfaces are stored as a photon map. In the second pass, rays are traced from the eye/camera until they hit a non-specular surface. The radiance value at the camera-ray hit point is then computed using density estimation (Jensen, 2001).

Photon mapping is an efficient way of simulating and visualizing daylight in buildings, including the effects of caustics, color bleeding, participating media, and subsurface scattering in scenes with complicated geometry and advanced material models (Jensen, 2004). With this method, it is possible to simulate advanced daylighting systems such as light pipes (Schou, 2012).

Surface properties and materials are described using the Fresnel equations, and include a range of plastic, metal and glass material types. Several predefined surfaces are available for each material type in order to provide realistic simulation inputs. Users can also specify custom surface properties with simple parameters covering RGB reflectance/transmittance, refraction, roughness and specularity values. The optical properties of window panes are defined by τ_v and refraction index.

Daylight Visualizer calculations have been validated against the CIE 171:2006 Test Cases to Assess the Accuracy of Lighting Computer Programs (CIE, 2006). The average error obtained in for all cases was below 1.63%, and it was found that Daylight Visualizer can accurately predict daylight levels and the appearance of a space lit with daylight. The simulation times are comparable or faster than e.g. Radiance (ENTPE, 2009).

Energy and Indoor Climate Visualizer

EIC Visualizer is based on the IDA ICE 4.0 simulation engine (Sahlin et al., 2004). The IDA ICE engine couples the airflow and thermal simulations, which is relevant for evaluations with focus on the effects of window openings, natural ventilation and solar shading (Sahlin, 2003).

Ventilation systems in EIC Visualizer can be natural, mechanical or a mix of the two (hybrid). The airflow model used in EIC Visualizer for natural ventilation is a pressure driven model. Cracks in the building façade and windows are defined with regards to airflow characteristics. The result is a calculation of natural airflows that considers infiltration through the façade and controlled natural ventilation through windows as one, i.e. these two components constitute the airflow and thus the natural ventilation rate of the building. The airflow of the mechanical system is included in the total ventilation rate of the building. The mechanical system can be exhaust only or balanced, with or without heat recovery.

Ventilation can be controlled based on one of two overall strategies, i.e. either "manual" control or demand control. A control for switching between mechanical and natural ventilation based on energy performance has been implemented in the latest version of the tool to allow evaluation of energy efficient hybrid ventilation.

The "manual" controls for natural ventilation are designed to mimic typical use of windows as providers of natural ventilation.

Demand controlled ventilation has been implemented in the latest version of EIC Visualizer and is based on CO_2 as indicator of air quality. The categories and associated CO_2 levels as defined in EN 15251 are used (cat. I: 750 ppm, cat. II: 900 ppm, cat. III: 1200 ppm).

Hybrid ventilation can reduce energy use in residential buildings. The hybrid ventilation control thus switches between natural and mechanical ventilation to minimise energy consumption. Mechanical ventilation with heat recovery is used when the outdoor temperature is low and there is a benefit from heat recovery. Natural ventilation has no energy consumption for air transport and is used when there is no heat loss associated with ventilation. The control algorithm is based on outdoor temperature.

Solar shading can be internal or external and is controlled based on the indoor temperature with the purpose of reducing overheating. Solar shading can also be based on specific real-world control solutions.

EIC Visualizer determines the electricity use for electric lighting. The switch-on set point is a user input as well as the luminous efficacy of the light source. For this algorithm, EIC Visualizer calculates the daylight level based on a simple radiosity model.

The IDA ICE engine has been validated as part of several studies, including validation exercises as part of IEA task 34 (Loutzenhiser et al., 2007), IEA task 22 (Achermann and Zweifel, 2003) and IEA task 12 (Achermann, 2000). A validation against CIBSE TM 33 showed good agreement between IDA ICE and CIBSE TM 33 (Moosberger, 2007).

Work process

Daylight and EIC Visualizer represent a first step towards an increased integration of daylight, thermal and air-flow simulations. During the design phase of a building, the tools should be used in an iterative process starting with an evaluation of the daylight performance followed by an evaluation of the energy and indoor climate performance. Design optimisations can be applied until a good balance is achieved between the daylight, energy, thermal comfort and air quality performance. The work process is illustrated in Figure 1.

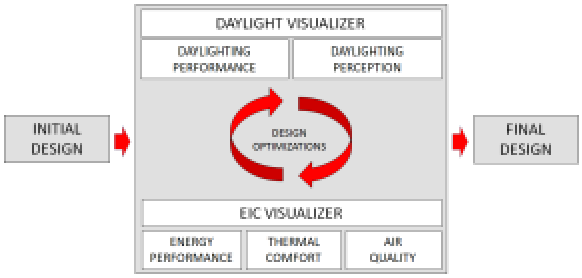

Figure 1. Work process for using the two tools.

RESULTS

Daylight Visualizer

The Daylight Visualizer results are image based and presented via an output viewer in which daylight conditions can be further analysed. The output viewer is presented in Figure 2.

It is possible to perform luminance, illuminance and daylight factor simulations. Luminance and illuminance levels can be calculated for three different view types: plan view, section view and perspective view. Whereas daylight factor levels can be calculated in the plan view and section view. The daylight calculations are performed with any of the 15 standard sky description from CIE (CIE, 2003). Figure 3 shows an example of an illuminance rendering and Figure 4 an example of a daylight factor rendering.

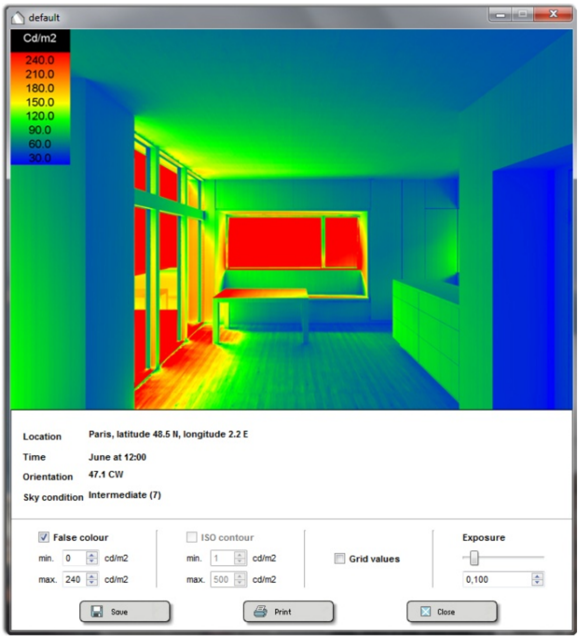

Figure 2. Output viewer of Daylight Visualizer showing a luminance rendering in false colour.

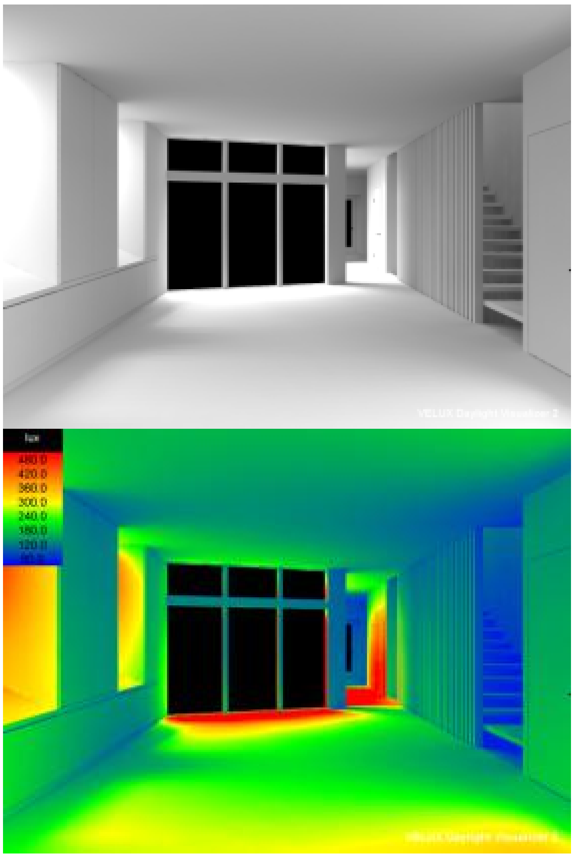

Figure 3. Illuminance rendering shown in its default visual output (above) and false colour (below).

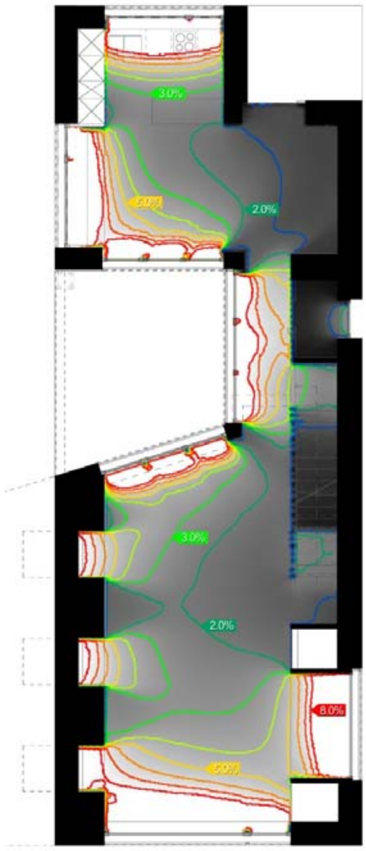

Figure 4. Daylight factor rendering of a ground floor with contour lines.

Simulation results are processed by applying false colour or contour lines mapping to the images in the output viewer. User can right click on the image to obtain the luminous values of pixels in the image, and they can use the left click to obtain the average value over a selected area in the image. It is possible to display a grid of numerical values, which provides a quick overview of the luminous values in the rendered images. Figure 5 presents a luminance rendering with contour lines applied and grid of numerical values.

Figure 5. Luminance rendering with contour lines and grid of numerical values.

When used in connection with plan views, the daylight factor and illuminance renderings have a function that automatically detects measurement areas in the model, with a 0.5 m border, as defined in EN 12464 (CEN, 2011).

Daylight Visualizer is also able to produce photo-realistic images, as shown in Figure 6 presenting a comparison between a luminance simulation (left) and a picture (right) from a realized project.

Figure 6. Comparison between luminance simulation (left) and picture (right) from the realized project.

Energy and Indoor Climate Visualizer

The EIC Visualizer results can be accessed at two levels. At the advanced level it is possible to obtain the results expected from general simulation tools, i.e. customizable charts detailing the building energy balance, temperatures, airflows, etc. on hourly basis.

The standard level of accessing results is based on a printable results report, which provides an overview of the energy performance of the building. Users without building simulation experience can select to have additional advice and guidance included in the report, which will assist them in the interpretation of the results. The results report is divided into sections on Energy, Thermal comfort, Ventilation, and Light.

The report can be generated for one building or as a report which compares results for several buildings. The comparison report is particularly useful for case studies.

Result on thermal comfort and indoor air quality are evaluated according to EN 15251 (CEN, 2007), and these results can therefore also be used for evaluations according to the Active House specification (Active House Alliance, 2011).

The thermal comfort results are based on the adaptive approach of EN 15251, using running mean outdoor temperature. Results within comfort categories I-III are categorized as “within comfort” range, while results within category IV are categorized as “outside comfort range”. Figure 7 presents an example of results based on the comfort categories.

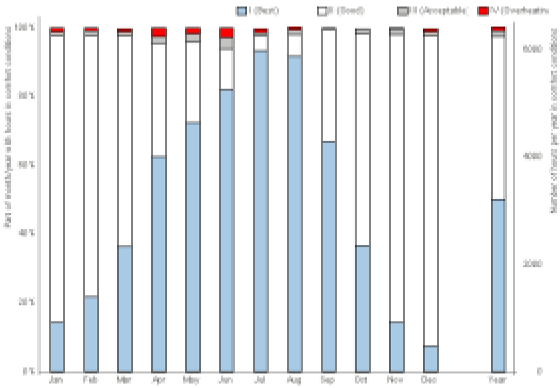

Figure 7. Presentation of thermal comfort categorized according to the categories of EN 15251.

Using the adaptive approach provides more meaningful results for naturally ventilated buildings than counting hours with a temperature above a specific threshold, especially in warm climates.

Operative temperatures can be displayed in a graph with the comfort range shown as a solid in the background for investigating of the thermal conditions on specific days or weeks, see Figure 8. The comfort range will change depending on outdoor temperature.

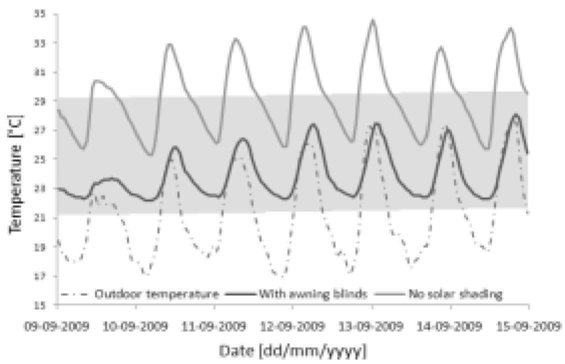

Figure 8. Presentation of operative temperature of the simulations with the comfort range (solid grey) based on running mean outdoor temperature.

The windows have a central role with regards to the energy performance of the building. The solar gains and heat loss through windows can be animated as an annual animation, including the effect of solar shading, if applied. Figure 9 presents an example of solar gains and heat loss through windows.

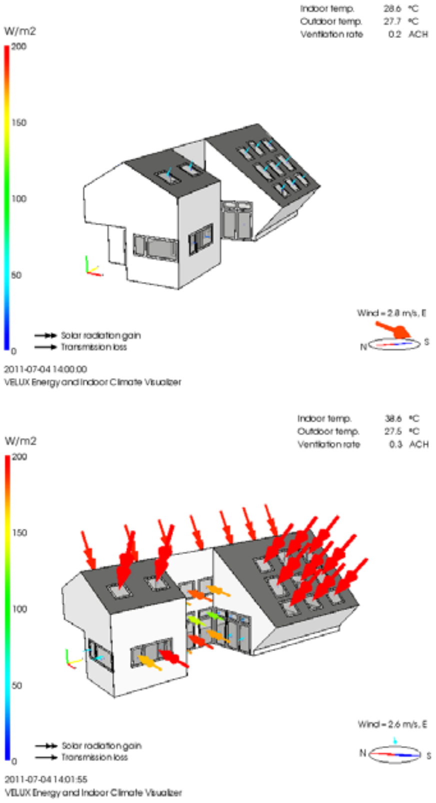

Figure 9. Snapshot from animation of solar gains and heat loss through windows. Top image shows a situation without solar shading, bottom image shows the same image with solar shading.

Ventilation rates and CO_2-levels are used together to indicate the air quality of the house. Four categories of CO_2-levels are used, based on the levels proposed in EN 15251, as the example in Figure 10 shows.

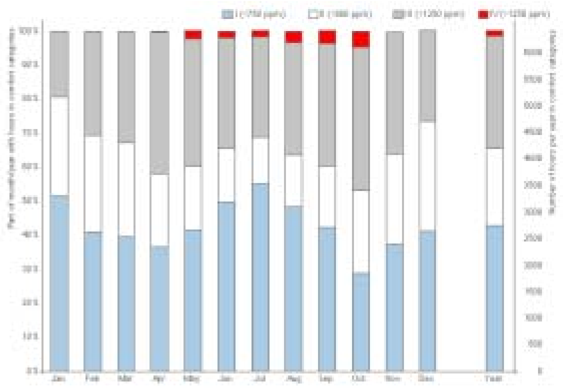

Figure 10. Presentation of Indoor Air Quality (based on CO_2) categorized according to the categories of EN 15251.

Natural ventilation flows through windows can be investigated through an annual animation. The airflows are visualised as coloured arrows with size and colour representing the flow magnitude, see Figure 11.

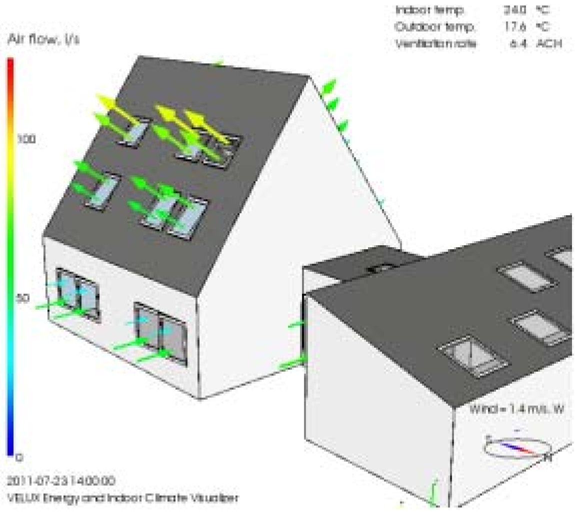

Figure 11. Snapshot from animation of airflows through windows.

Typically a time range of a day or less is selected in a period where external conditions relevant to the specific investigation occur. The animation can be used to explore how the combination of ventilation controls and natural driving forces determine the magnitude and distribution of the airflows. It can be used to investigate stack effect, cross and single sided ventilation under different weather conditions.

FUTURE WORK

The development of Daylight and EIC Visualizer is a continuous process and further integration between the tools is intended.

Annual climate-based simulations in Daylight Visualizer and support for BSDF will permit to include the effects of direct solar radiations and solar shading on the daylighting performance. This will align the simulation methods used in the tools and make it possible to exchange simulation data including the frequency of solar shading utilisation, hourly daylight levels and occupancy profiles.

Results will be automatically processed and presented in a common report to simplify results interpretation. In addition, the report will include specific building standards and labels to support their correct use and adoption by practitioners.

CONCLUSION

VELUX Daylight and EIC Visualizer target residential buildings as a supplement to mandatory compliance evaluations of energy performance. The purpose is to offer tools that are easy to use, yet sufficiently detailed to evaluate the effects of windows, natural ventilation and solar shading on the quality of indoor environments.

The simple user interface design, progress bars, predefined settings, automated modelling, results presentation, and evaluation of performance based on European standards contribute to the ease-of-use of the tools by building professionals.

The coupled airflow and thermal model, daylight model, option for demand-controlled ventilation, and range of control options for ventilation and solar shading contribute to simulations sufficiently detailed for use in the conception and realization of residential buildings with dynamic window systems.

Accurate and user-friendly simulation tools could lead to an increased use of performance-based evaluations in the design of single-family house projects.

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