Advanced and future simulation tools

T50.C5

A Technical Report of IEA SHC Task 50

Advanced Lighting Solutions for Retrofitting Buildings

April 6, 2016

IEA Solar Heating and Cooling Programme

The Solar Heating and Cooling Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency. Its mission is *"to enhance collective knowledge and application of solar heating and cooling through international collaboration to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050.*

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- Daylighting/Lighting (Tasks 21, 31, 50)
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Advanced and future simulation tools

A Technical Report of Subtask T50-C5

IEA SHC Task 50: Advanced Lighting Solutions for Retrofitting Buildings

2016-04-06

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PREFACE

Lighting accounts for approximately 19 % (~3000 TWh) of the global electric energy consumption. Without essential changes in policies, markets and practical implementations it is expected to continuously grow despite significant and rapid technical improvements like solid-state lighting, new façade and light management techniques.

With a small volume of new buildings, major lighting energy savings can only be realized by retrofitting the existing building stock. Many countries face the same situation: The majority of the lighting installations are considered to be out of date (older than 25 years). Compared to existing installations, new solutions allow a significant increase in efficiency – easily by a factor of three or more – very often going along with highly interesting payback times. However, lighting refurbishments are still lagging behind compared to what is economically and technically possible and feasible.

IEA SHC Task 50: Advanced Lighting Solutions for Retrofitting Buildings" therefore pursues the goal to accelerate retrofitting of daylighting and electric lighting solutions in the non-residential sector using cost-effective, best practice approaches.

This includes the following activities:

- Develop a sound overview of the lighting retrofit market
- Trigger discussion, initiate revision and enhancement of local and national regulations, certifications and loan programs
- Increase robustness of daylight and electric lighting retrofit approaches technically, ecologically and economically
- Increase understanding of lighting retrofit processes by providing adequate tools for different stakeholders
- Demonstrate state-of-the-art lighting retrofits
- Develop as a joint activity an electronic interactive source book ("Lighting Retrofit Adviser") including design inspirations, design advice, decision tools and design tools

To achieve this goal, the work plan of IEA-Task 50 is organized according to the following four main subtasks, which are interconnected by a joint working group:

Subtask A: Market and Policies
Subtask B: Daylighting and Electric Lighting Solutions
Subtask C: Methods and Tools
Subtask D: Case Studies
Joint Working Group (JWG): Lighting Retrofit Adviser

ABSTRACT

The document reflects a study about the so called “advanced and future simulation tools”. The denominated software is able to simulate Complex Fenestration Systems (CFS) which are composed of solar shading and daylight redirection systems. Those systems might have complex light transmission properties named Bidirectional Transmission Distribution Functions (BTDF) that can be monitored using gonio-photometers or simulated using ray-tracing tools. Five tools able to simulate CFS were examined in a variant of the refurbished case study of C2. Four kinds of CFS were considered, ranging from clear glass to lasercut panel, and were benchmarked with daylight factor values on the work plane and renderings in sunny conditions. The results showed a large discrepancy in the results for the daylight factor values, indicating the difficulty to simulate daylight likewise in the document C2. The renderings with sunny conditions let the user of the tools appreciate the deviation effect of the lasercut panel for instance, but the obtained images are bound to the intrinsic resolution of the monitored BTDF which may be coarse depending on the source of data. The advanced and future simulation tools can give an interesting indication of the light distribution through CFS, but practitioners should remain aware of the limits of the method using monitored data bound to a defined resolution. The results are satisfactory enough to get an idea of illuminance profiles or even heat transmission, but not for tasks that require a precise luminance distribution such as glare index calculation.

EXECUTIVE SUMMARY

Complex fenestration systems, composed principally of solar shadings and daylight redirection devices, can contribute to mitigating the energy consumption of buildings through reduction of thermal load and electric lighting consumption. Bidirectional light transmission properties of such systems (BTDF, Bidirectional Transmission Distribution Function) can be monitored using bidirectional goniophotometers. The emerging standard for data storage and simulation seems to be the Window XML format, which is considered in this study.

Computer simulation programmes for the design and visualisation of complex fenestration systems located on-site (transmission of direct and diffuse daylight components) can facilitate and promote the use of CFS by architects, lighting designers and building practitioners. Advanced simulation tools aiming at daylighting and electric lighting systems within retrofit projects are considered as well as (future) tools under development.

The following tools are examined: DIALux evo, Fener, Geronimo, Radiance, Relux-Pro.

They are applied to a special case study with 3 windows fully equipped of the following BTDFs in Window XML format:

- Clear glazing,
- Clear glazing with diffuse blinds,
- Clear glazing and vertical venetian blinds,
- Redirecting CFS: Lasercut panel.

The tools were compared by means of different benchmarking exercises such as:

- Daylight factor values on the workplane (CIE overcast sky),
- Renderings with sunny conditions,
- Annual characteristics (daylight autonomy).

The analysis of the dispersion of the results between the different tools shows that the discrepancies are rather large between the different tools. This result may be explained by the diversity within the 3D models employed for the simulations and within the rendering parameters. Indeed, discrepancies were found even between software with similar simulation engines (RADIANCE for example). Due to the multiplicity of the potential error sources (including the ones from the users of the tool), a final conclusion is hard to draw. However, we can note that the quality of the rendering depends on the resolution of the BSDF itself, which, in the cases studied is very coarse. In its actual state, the simulation tools can give an indication of the light distribution in the room satisfactory enough to get an idea of illuminance profiles.

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1. Introduction

An advanced use of daylight in refurbished buildings implies the use of transparent construction materials in building façades. Those should provide the needs of the occupants through different functions:

- Contribution to the room lighting;
- Provision of solar gains displacing the heating needs;
- Fresh air requirements through natural ventilation;
- Visual contact to the exterior of the building;
- Thermal and acoustic isolation with the exterior.

In order to fulfil the previous functions, the façade can be subdivided in two principal zones: a median zone to provide a view on the exterior and an upper zone dedicated to an optimal daylight flux control. Figure 1 illustrates the presence of the median and upper zones in an experimental and demonstration daylight module located on the campus of EPFL (Switzerland). In addition to the presence of transparent materials, solar protection systems are generally placed on the façade to reduce glare risks and overheating for the occupants.

Figure 1: Inside view of one of the experimental and demonstration modules in daylight DEMONA located on the EPFL campus (Switzerland)

When refurbishing a building, the choice of transparent material can be set to standard double or triple glazing or to more advanced glazed systems. The latter named Complex Fenestration Systems (CFS) is a family composed of both **solar protection** and **daylight redirection systems** which can contribute more efficiently to mitigate the energy consumption of buildings through the reduction of thermal load and electric lighting consumption. Figure 2 illustrates two complex fenestration systems placed in the upper part of the façade. The impact of the two systems on the daylight flux is compared with the one of a standard insulating glazing placed at the same location (cf. Figure 2).

Figure 2: Interior view of daylight modules DEMONA equipped with different complex fenestration systems on the upper part of the façade : (top) standard insulating glazing, (centre) laser cut panel and (bottom) 3M SOLF prismatic film; left and right images have different exposure times.

Many complex fenestration systems have been examined during International Energy Agency Tasks focusing on daylight (IEA SHC Task 21, IEA ECBCS Task 45, IEA Task 31). Luminous transmission properties of a complex fenestration system, designated by Bidirectional Transmission Distribution Function (BTDF), indicate how much light falling on the system is redirected inside the building. Figure 3 shows such data for a solar protection system from Baumann-Hüppe AG using a polar diagram. An important daylight flux impinging with an angle of 60° is redirected by the lamellas towards the ceiling.

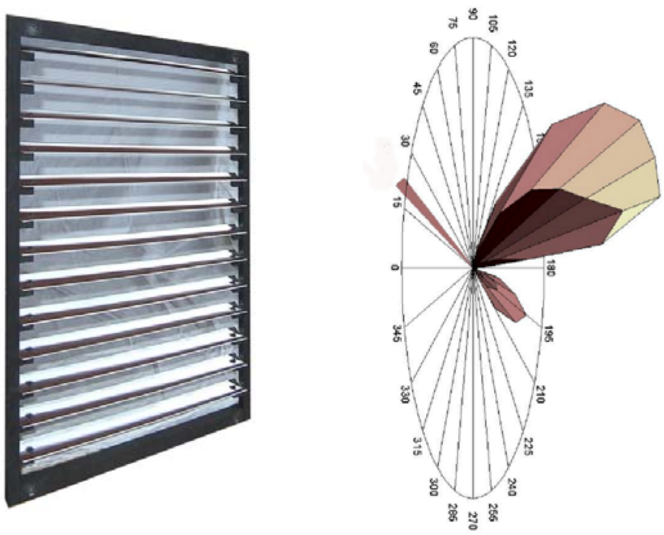


Figure 3: BTDF of a solar protection system provided by Baumann-Hüppe AG (And04)

The BTDF of a complex fenestration system, also named « Coefficient de luminance q », was introduced by the Commission Internationale de l'Eclairage in 1977 (CIE77) and is given by the following equation:

$$BTDF(\vartheta_1,\phi_1,\vartheta_2,\phi_2) = \frac{L_2(\vartheta_1,\phi_1,\vartheta_2,\phi_2)}{E_1(\vartheta_1)} = \frac{L_2(\vartheta_1,\phi_1,\vartheta_2,\phi_2)}{L_1(\vartheta_1,\phi_1)\cdot \cos\theta_1 \cdot d\omega_1},$$

where the different symbols represent:

- (ϑ_1,ϕ_1) and (ϑ_2,ϕ_2) are the polar coordinates of the incident and outgoing light fluxes in degrees;
- $L_1(\vartheta_1,\phi_1)$ and $L_2(\theta_1,\phi_1,\vartheta_2,\phi_2)$ are the luminances of the incident and outgoing elementary light flux in cd.m^{-2};
- $d\omega_1$ is the solid angle of the incident elementary light flux in sr;
- $E_1(\vartheta_1)$ is the illuminance due to the incident light flux on the system in lx.

The origin of the coordinate system, which defines the four independent variables in $BTDF(\vartheta_1,\phi_1,\vartheta_2,\phi_2)$, is placed on the outside of the system.

Nowadays, this definition has been extended to include the reflected component of light named the Bidirectional Reflection Distribution Function (BRDF) and define the complete light behaviour of a system named Bidirectional Scattering Distribution Function (BSDF). The monitoring of BSDF is realized using a measuring device named goniophotometer, several of which are in use throughout the world:

- Bidirectional goniophotometer using digital imaging technique at EPFL, Switzerland. Resolution of 145 input Tregenza zones and 5° by 5° in azimuth and elevation for the output zones, based on CCD imaging technique. The CCD camera is equipped with a v(lambda) filter and calibrated in order to monitor luminance values, giving transmission distribution functions corresponding to the visual response of the light.
- pgII bidirectional photogoniometer at Fraunhofer ISE, based on mechanical scanning of a detector head with multiple sensors over a virtual sphere surface that is centred on the intersection between the incident beam and the sample. The sample can be rotated around vertical and horizontal axes to allow any angle of incidence. The detector head includes broadband sensors for the visible and NIR ranges, and a diode array spectrometer covering most of the solar spectral range. When a laser is used as the light source, an angular resolution of better than 1 mrad can be achieved. A tungsten halogen lamp and a xenon lamp are also available as light sources.
  The same device without spectrometer is installed at LBL, California, USA, and at HSLU Luzern, Switzerland,
- Bidirectional goniophotometer using digital imaging technique at Fraunhofer-IBP, Stuttgart, Germany. Standard Resolution of 145 input Tregenza zones (others upon request) and 2° by 2° in azimuth and elevation for the output zones, based on CCD imaging technique. The CCD camera is equipped with a v(lambda) filter, CIE x,y,z filters and a c(lambda) filter. Transmission (BTDF) and reflection (BRDF) can be recorded. The test stand is equipped with an automated positioning system for blind louvres (tilt angle and distance between slats).

For certain situations, in which the optical properties of the translucent and opaque components of a fenestration system are available, BSDF datasets of full fenestration systems can be calculated analytically or through ray-tracing. Tools such as Window and

Fener are able to calculate BSDF datasets of systems composed of layers for which an analytic optical model can be derived (e.g. transparent glazing and diffusive shades). One example of raytracing tool is the Radiance-based genBSDF, which uses the Radiance engine to generate BSDF datasets of geometrically complex fenestration components such as venetian blinds.

BSDF datasets contain a large number of coefficients and are difficult to visualize and compare. A freely available tool, BSDF Viewer was developed at LBNL to be able to easily visualize BSDF datasets. Figure 4 depicts a visualisation of the transmission properties of venetian blinds.

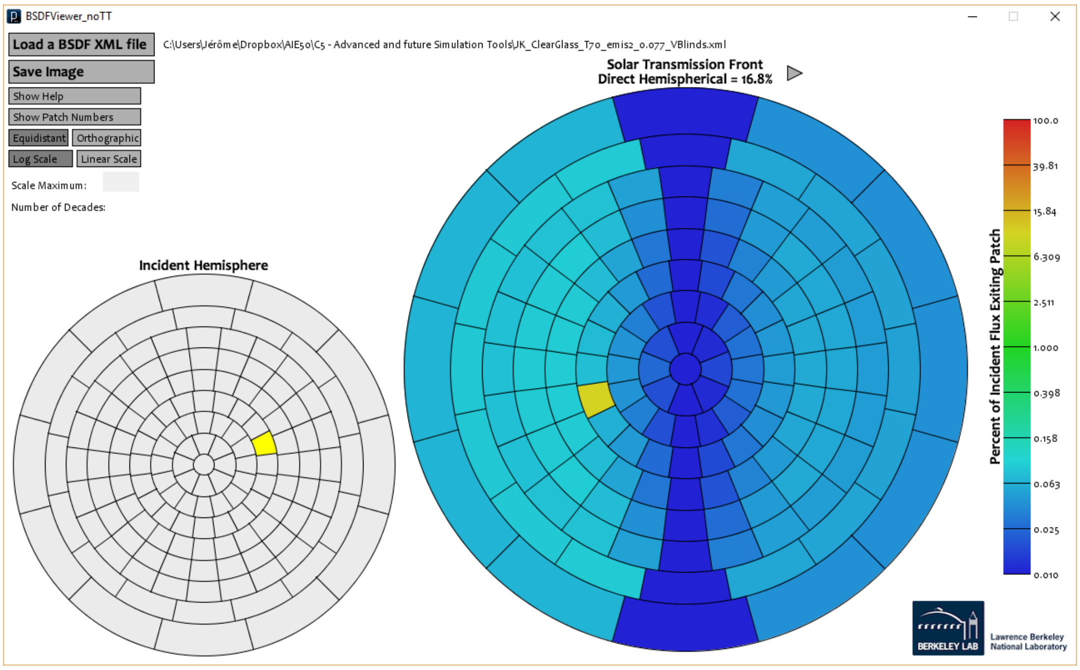


Figure 4: BSDF of Venetian blinds, visualisation with BDSFViewer v.1.2 for Windows

A first standard for the storage of BTDF data was set during the International Energy Agency Tasks 21 focusing on daylight (IEA SHC Task 21). Nowadays, an international standard has emerged for the storage of BSDF data in an XML format taken from Window 6 (LBNL), with which all mentioned goniophotometers are compatible.

Advanced and future simulations tools for the design and visualisation of complex fenestration systems located on-site (transmission of direct and diffuse daylight components) can facilitate and promote the use of CFS by architects, lighting designers and building practitioners. As mentioned, the benefits for using CFS for retrofitting buildings can be manifold: reducing the thermal load and the electric lighting consumption.

When the use of CFS is not rational in retrofitting the buildings, the choice must be made to use efficient electric light sources such as LEDs which require specific lighting fixtures. Indeed, LEDs are intense and punctual light sources that need fixtures to distribute the light flux as uniformly as possible in a given direction. In order to design and visualise LED lighting systems, manufacturers estimate their light distribution and spectrum through simulation or measurement by goniometers (see Figure 5). The resulting candle-power distributions are saved in international standards (IES and Eulum.dat) that can be used by common simulation tools (listed in the C2 document).

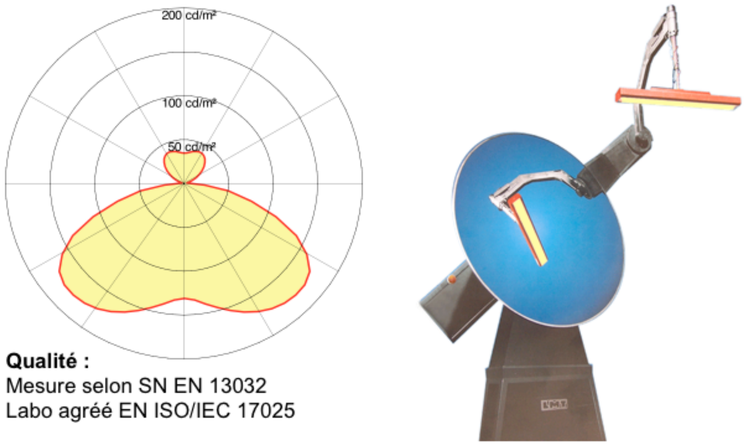


Figure 5: Goniometer for electric lighting systems to produce IES / Eulum.dat files for simulation

Advanced simulation tools aiming at daylighting and electric lighting systems within retrofit projects should be able to do lighting simulations on the basis of BSDF data stored in the Window 6 XML format for the daylight, and IES/Eulum.dat format for electric lighting. Considering that the latter can be realised by standard simulation tools, the focus in what follows is placed on advanced simulations tools for daylighting that can achieve simulations of complex fenestration systems using BSDF data. They are reviewed and applied to a case study of building retrofit and compared through a benchmarking exercise.

2. Review of existing advanced simulation tools for complex fenestration systems

In this section the different simulation tools described in Subtask-C2 are reviewed for their advanced functions for complex fenestration systems.

2.1. DIALux evo

Source: J. de Boer / Fraunhofer Institute of Building Physics, Stuttgart, Germany

For general information on the DIALux evo program please refer to Section 5.3 of Subtask C2 report.

Advanced functions for Complex Fenestration Systems

With regard to complex fenestration systems an approach based on using measured BTDF data is included. From the sky illuminance distribution and the system data, candle power distributions are calculated allowing to then perform the CFS calculation within the software (rf. to Figure 6). In a layer model, combinations of different glazing types and BTDF based CFS can be employed. Backbone of the CFS inclusion in DIALux evo is a data base of CFS measured in a goniophotometer. The more than 50 components from currently 7 manufacturers comprise venetian blinds, light guiding glasses, and components for rooflights. As the used goniophotometer can provide colour-resolved data (CIE XYZ), in parts also colour effects can be regarded (e.g. coloured blinds, colour bleeding effects in the adjacent spaces).

The functionality is embedded into a user friendly graphical user interface. This allows, to configure the glazing, sun- & glare protection (CFS) unit or the rooflight element (rf. to Figure 7). Sun- and glare protection systems and rooflights are assessed via plugins, managed and provided by the specific manufacturers (rf. to Figure 8).

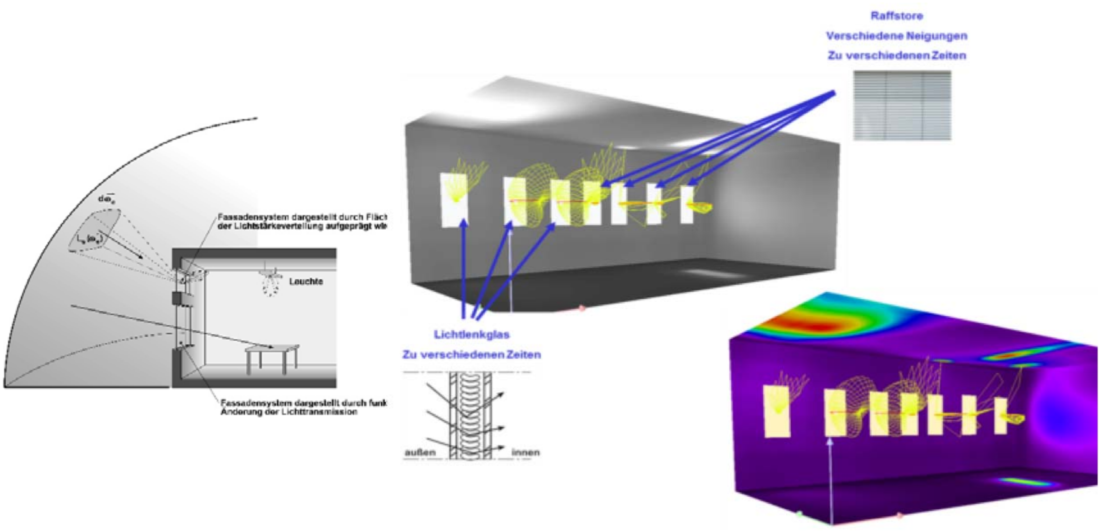


Figure 6: Calculation principle. Use of candle power distributions of CFS in DIALux evo

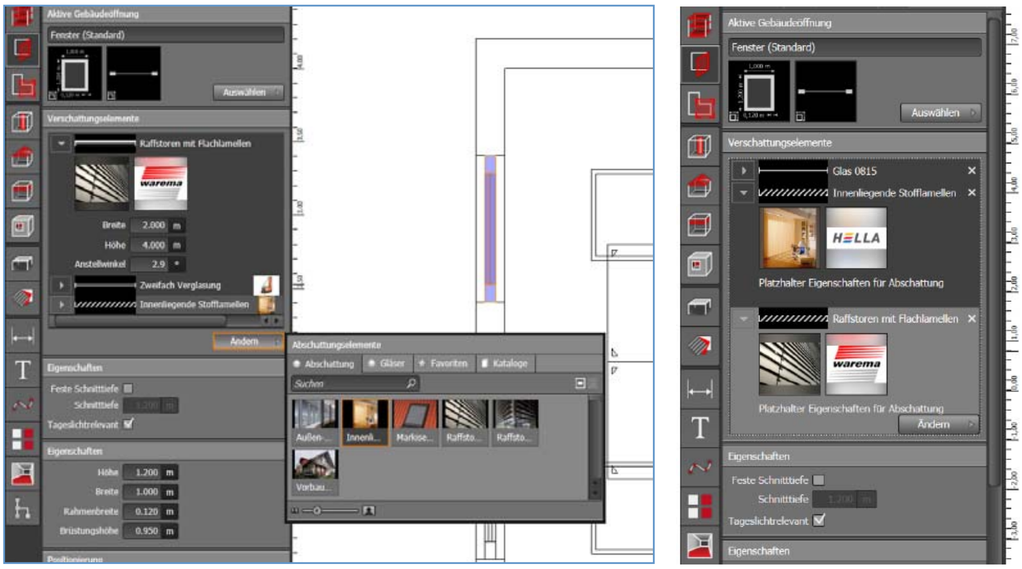


Figure 7: Component selection (left) and definition of layer model (right)

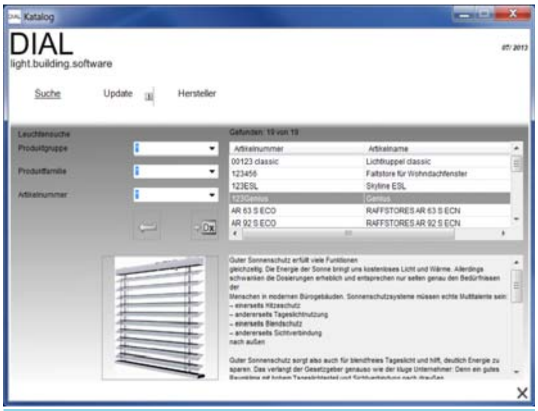


Figure 8: Example of a plugin

Import/export

Photometric data, data on system employment (e.g. control curves) and product information are contained in a XML data format.

2.2. Fener (ISE)

Source: B. Bueno / Fraunhofer Institute for Solar Energy Systems ISE, Freiburg Germany

For general information on the Fener program please refer to Section 5.6 of Subtask C2 report.

Advanced functions for Complex Fenestration Systems

In Fener, fenestration systems are basically represented by the following two datasets (see Figure 9):

- BSDF for the optical performance, and
- calorimetric data (angular dependent g-values) for the thermal performance.

The model integrates energy, daylighting and glare simulations in a time-step basis, being very flexible in simulating shading control strategies that depend on thermal or visual comfort variables.

The following methodologies are used in Fener:

- Building energy balance: the thermal representation of the fenestration system is based on angularly resolved solar heat gain coefficients (g-values), which can be analytically derived or obtained through calorimetric measurements. A heat balance method is implemented to calculate hourly building energy demand.
- Indoor irradiances and illuminances: Fener uses the three-phase method to calculate the energy and light optical transmission through the fenestration system.
- Glare: Fener implements the Enhanced Simplified and the Simplified DGP methods to evaluate glare.

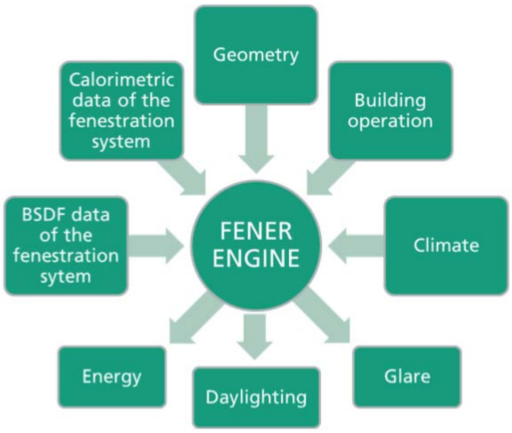


Figure 9: Diagram of the simulation engine Fener

Import/export

The user can import weather data files in epw format and bi-directional scattering distribution function (BSDF) datasets in XML format. Simulation outputs can be exported in XML files.

References

B. Bueno, J. Wienold, A. Katsifaraki, T.E. Kuhn. Fener: a Radiance-based modelling approach to assess the thermal and daylighting performance of complex fenestration systems in office spaces. Energy and Buildings 94 (2015) 10–20.

T.E. Kuhn, S. Herkel, F. Frontini, P. Strachan, G. Kokogiannakis. Solar control: A general method for modelling of solar gains through complex facades in building simulation programs. Energy and Buildings 43(1) (2011) 19-27.

T.E. Kuhn. Calorimetric determination of the solar heat gain coefficient g with steady-state laboratory measurements. Energy and Buildings 84(0) (2014) 388-402.

2.3. GERONIMO

Source: C. Basurto & J. Kaempf / LESO-PB- EPFL, Switzerland

For the general description of the Geronimo program please refer to Section 5.7 of Subtask C2 report.

Advanced functions for Complex Fenestration Systems

Geronimo allows visualizing the impact of Complex Fenestration Systems (CFS) in office buildings for two different sky types (overcast and clear skies). The input data can be derived from a gonio-photometer in IEA 21 format but also in Window XML format. Geronimo uses the RADIANCE engine to provide the renderings.

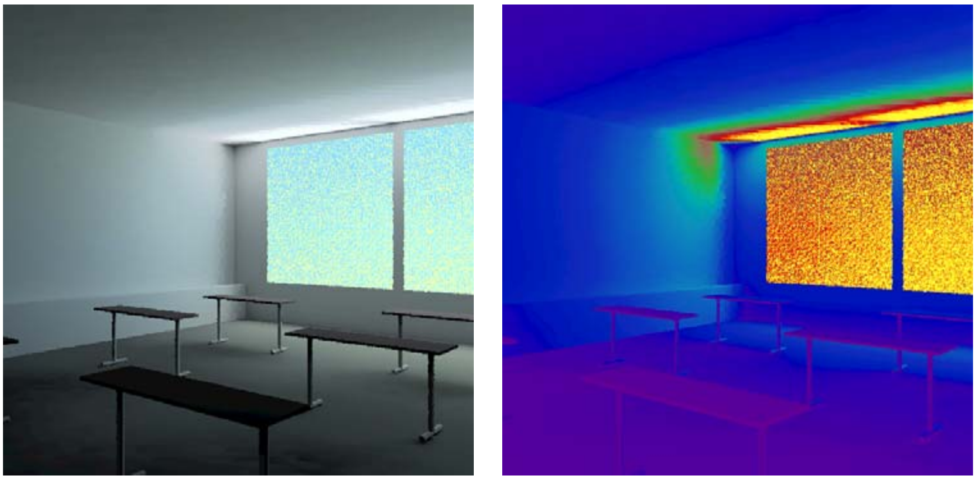


Figure 10: Laser cut panel simulated under a clear sky, human vision rendering (left) and illuminance rendering (right)

Import/export

The BTDFs files described in the IEA-21 Task can be imported and converted into the Window XML format used by RADIANCE for the ray-tracing simulations. Images are exported in BMP format and illuminance values in text file format.

2.4. Radiance

Source: D. Geisler Moroder / Bartenbach GmbH, Aldrans, Austria

For the general description of the Radiance program please refer to Section 5.10 of Subtask C2 report.

Advanced functions for Complex Fenestration Systems

To better account for specular reflections, Radiance does not only work with matrix based BSDF data, but is also able to generate and use variable-resolution BSDFs. The 3- and 5-phase-methods allow users to efficiently perform annual daylight calculations even including complex daylighting systems that are characterized by their BSDFs.

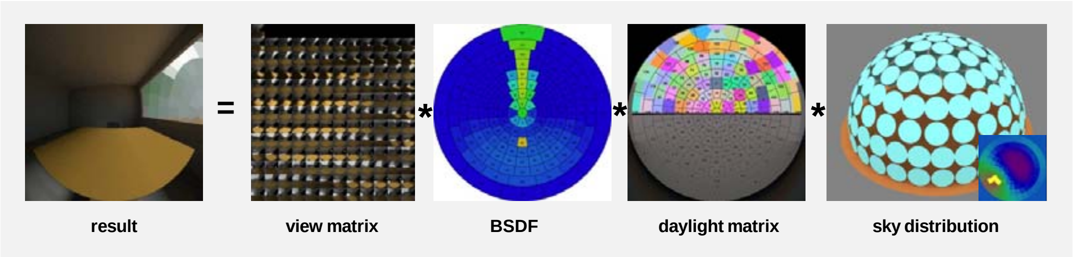


Figure 11: Schematic diagram of the calculation steps of the 3-phase-method

Moreover, Radiance allows a combined usage of a system's BSDF and its geometry to provide an improved calculation of the direct sun contribution as well as a more realistic visualization.

Figure 12: Simulation of a daylighting system represented by its BSDF (left) and by a combination of BSDF and geometry (right)

Evaluation tools that e.g. allow the calculation of glare indices such as the Guth VCP, UGR, DGI or DGP complement the Radiance software toolkit.

Import / Export

BTDFs files that are described in the Window XML format can be imported for the ray-tracing simulations. Standard formats include Klems‘ full, half or quarter representation (145x145, 73x73 or 41x41 patches), but all other discretizations can be used if properly defined in the XML header.

2.5. ReluxPro

Source: J. Kaempf, LESO-PB, Ecole Polytechnique Fédérale de Lausanne, Switzerland

For the general description of the ReluxPro program please refer to Section 5.11 of Subtask C2 report.

Advanced functions for Complex Fenestration Systems

ReluxPro embeds a set of 3 CFS in their database coming from measurements of the gonio-photometer at LESO-PB/EPFL: Film 3M (exterior and interior), Saint-Gobain Lumitop and Solartran Laser-cut panel (see Figure 13). In order to proceed with CFS rendering, the ray-tracing engine must be chosen (and not the radiosity).

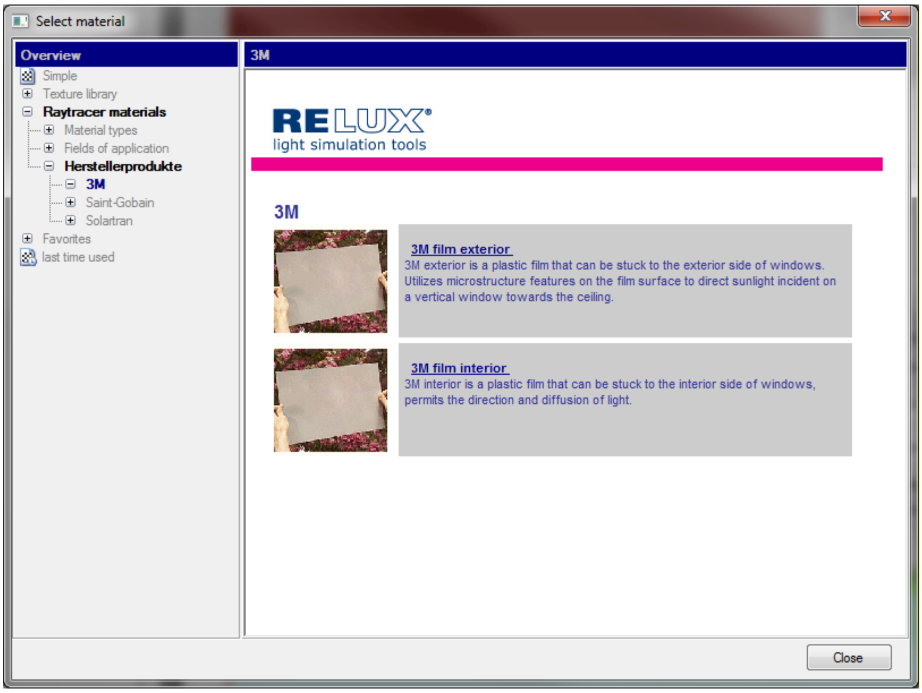


Figure 13: Selection of the CFS material within ReluxPro

Import/export

There is no import feature for CFS in Window XML format. However, there is a functionality to add other CFSs within ReluxPro.

3. Testing of the tools on a case study for retrofitting buildings

3.1. Description of the case study

The case-study is similar to the one described for C2 refurbished except that the glazed area of south-East facade is fully replaced by CFS. The dimensions of the glazing are described in the figure below.

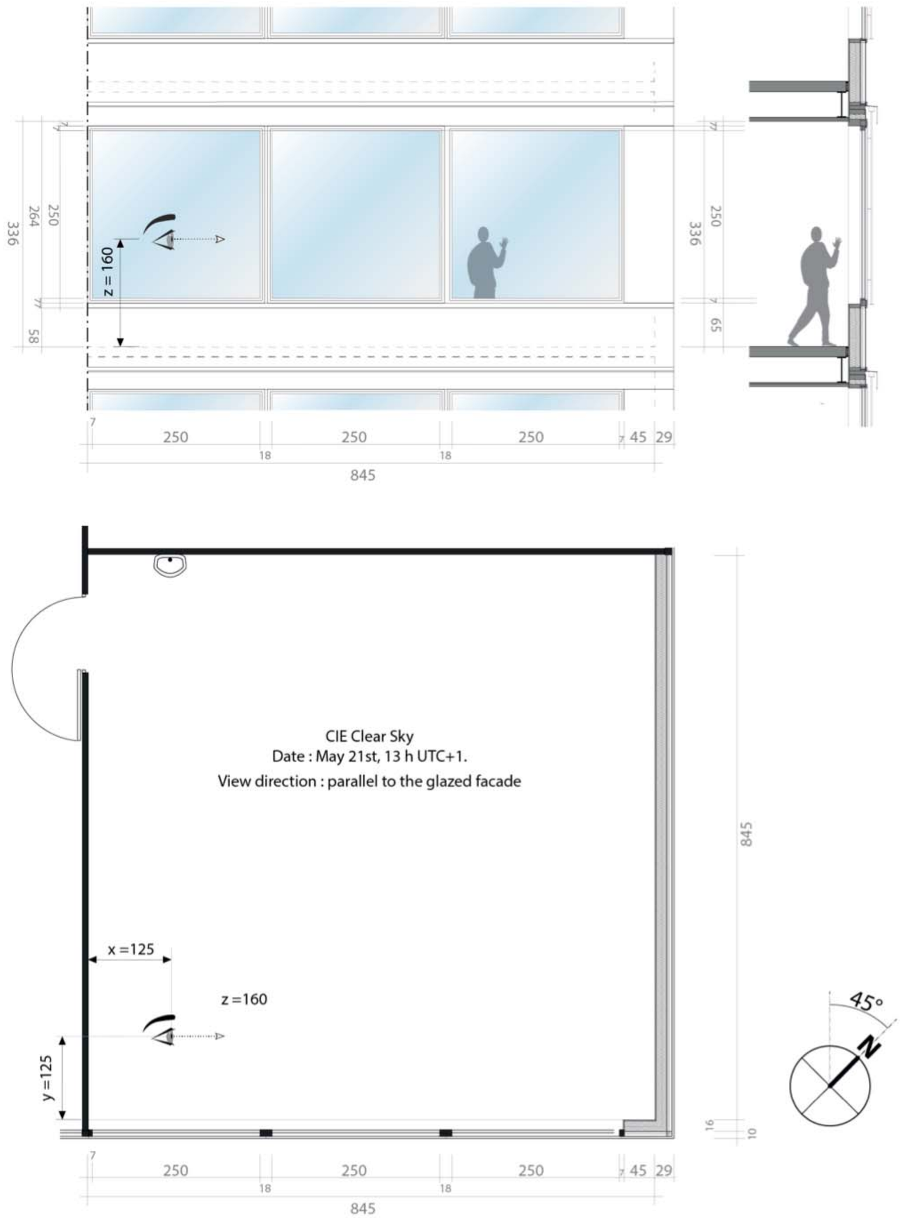


Figure 14: Schematic description of the room parameters for simulations with CFS

Simulation conditions

The expected results for each simulation tool are as follow:

- Daylight factor values on the workplane level.
- Renderings with sunny conditions:
    - CIE Clear Sky, Date: May 21st, 13 h UTC+1
    - View direction: parallel to the glazed façade

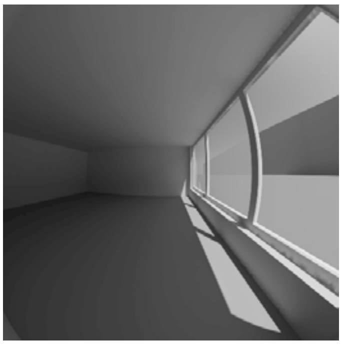


Figure 15: RADIANCE rendering with clear glass from the described view-point (sunny sky conditions, source D. Geisler-Moroder)

Four types of CFS are tested:

1. Clear glazing
   Double Clear Standard Glass with Visible Transmittance 0.691.

2. Clear glazing with Diffuse roller blind
   Double Clear Glass, Visible Transmittance 0.691 with Exterior Diffusive Roller Blind, Visible Transmittance 0.287.

3. Clear glazing and Venetian Blinds (0°)
   Double Clear Glass, Visible Transmittance 0.691 with Exterior Vertical Blinds of a diffusing shade material, slats width 16mm and spacing of 12.0mm, with a tilt of 0°, fully open.

4. Redirecting CFS: Lasercut Panel
   The LCP system is based on the principles of light deflection and internal reflection when passing through a parallelepiped as shown in Figure 16, when direct sunlight passes through LCP, the larger portion of light is deflected upwards while a portion of the light is reflected to the exterior, however the proportion and redirection of the light depends on the incident angle. LCP is defined by four parameters: the distance between the cuts, the distance the cuts extend the through the sheet, the angle of the cuts relative to the normal and the refractive index of the material.

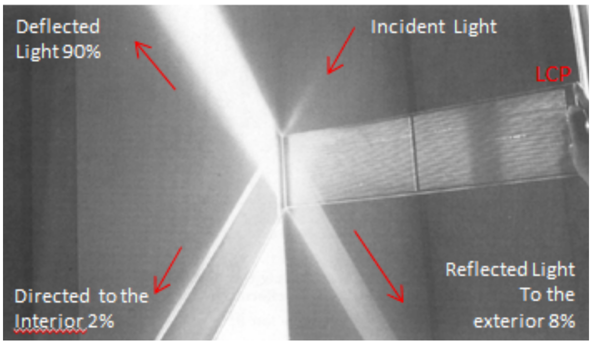


Figure 16: A view that shows the deflected, reflected and redirected incident light when passing through the LCP

LCP is produced from a plastic or acrylic sheet divided into arrays of laser cuts that produce internal reflecting interfaces in the material. Its installation would require the use of one or two sheets of glass for protection. Figure 17 shows a cross-section of two LCP laminated between two glass sheets of 1.5 mm, the upper panel is 6 mm thick while the lower panel is a panel of 5.5 mm between two glass sheets. The application of LCP can be in sidelight windows, skylights or incorporated in tilt able slats in which the tilted angle should be adjusted according to the angle of the sun's incidence on the panel [85]. One of the main advantages of LCP is its transparency that contributes to the view to the outside as shown in Figure 18.

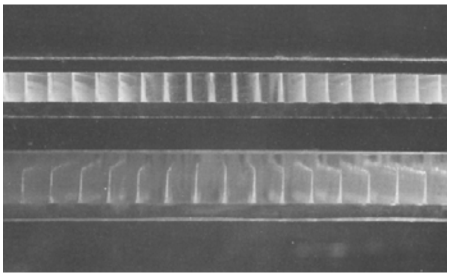


Figure 17: Cross-section through LCP showing a panel of 6mm thick (up) and a panel of 7mm thick (down)

Figure 18: A close view of LCP that shows the transparency of the panel to contribute to a better view of the exterior environment

3.2. Results of the tools on the case study

3.2.1. Results from DIALux evo 6

Source: Jan de Boer / Eike Budde

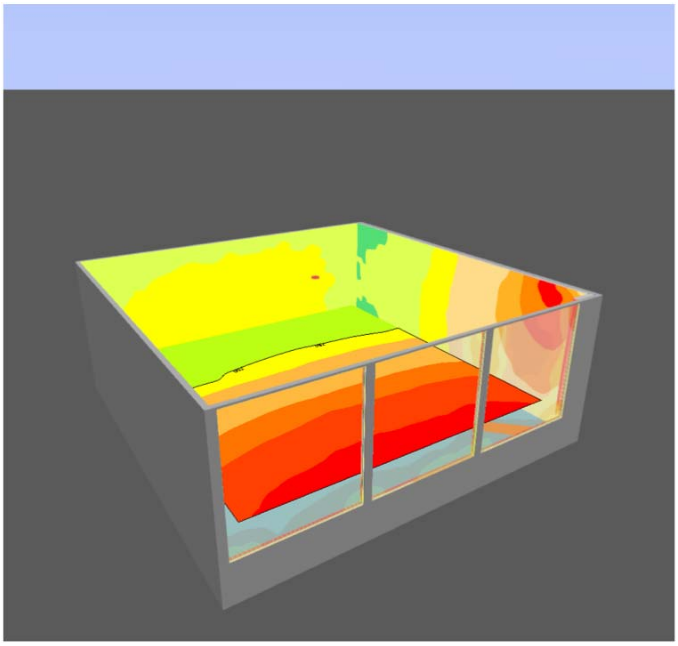
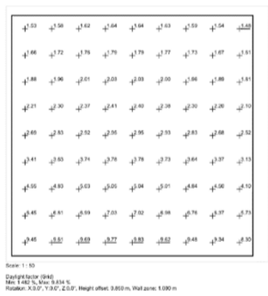


Figure 19: Visualization of model with "DIALux evo 6"

DOUBLE CLEAR GLASS (IBP Measured Data)

Daylight factor
Max: 9.83 %
Mean: 3.87 %
Min: 1.48 %



Rendering

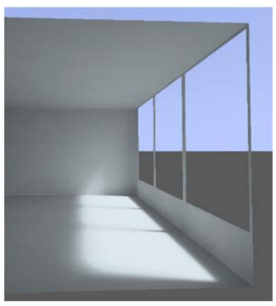


Figure 20: Daylight factor values and rendering for double clear glass with DIALux evo 6

DOUBLE CLEAR GLASS WITH DIFFUSE BLINDS (IBP Measured Data)

Daylight factor

Max: 2.43 %
Mean: 1.11 %
Min: 0.47 %

Rendering

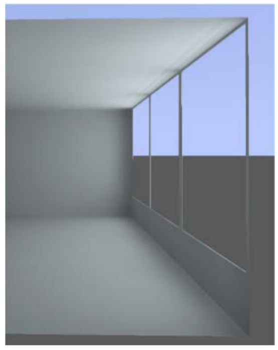


Figure 21: Daylight factor values and rendering for double clear glass with diffusive blinds with DIALux evo 6

LASERCUT PANEL (Lasercut_Panel_145x1297.xml)

Daylight factor

Max: 4.42 %
Mean: 2.14 %
Min: 1.04 %

Rendering

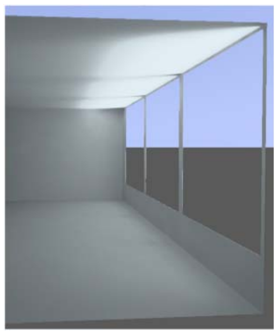


Figure 22: Daylight factor values and rendering for laser cut panel with DIALux evo 6

3.2.2. Result from Fener

Source: B. Bueno / Fraunhofer ISE

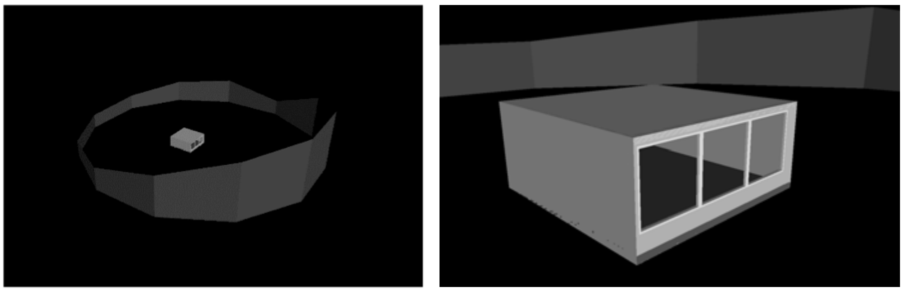


Figure 23: Visualization of model with "rshow"

Grid of sensor point

- distance from interior surfaces: 0.5 m
- sensor height: 0.8 m

Simulation period (Daylight Autonomy)

- Period: July and August not considered
- Time: 8am – 6pm

DOUBLE CLEAR GLASS (JK_ClearGlass_T70_emis2_0.077.xml)

Daylight factor

Max: 14.49 %
Mean: 4.05 %
Min: 0.81 %

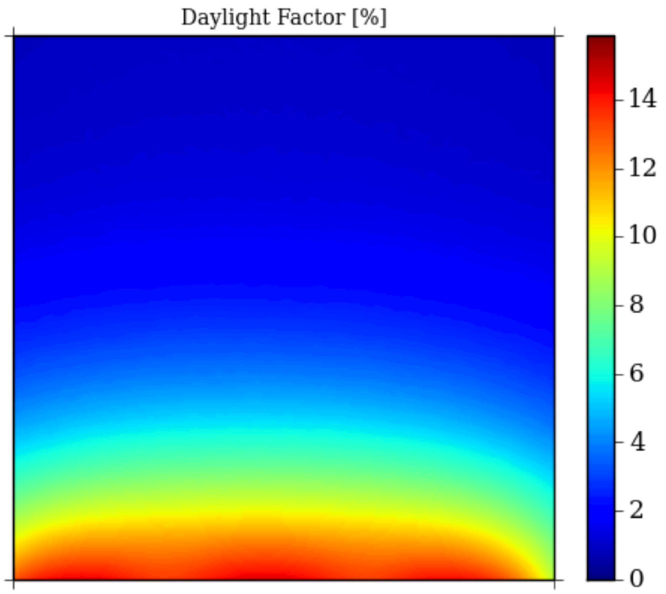


Figure 24: Daylight factor values for double clear glass with Fener

Daylight Autonomy

$sDA_{300,50\%}$ = 76.96%

(July and Aug not considered)

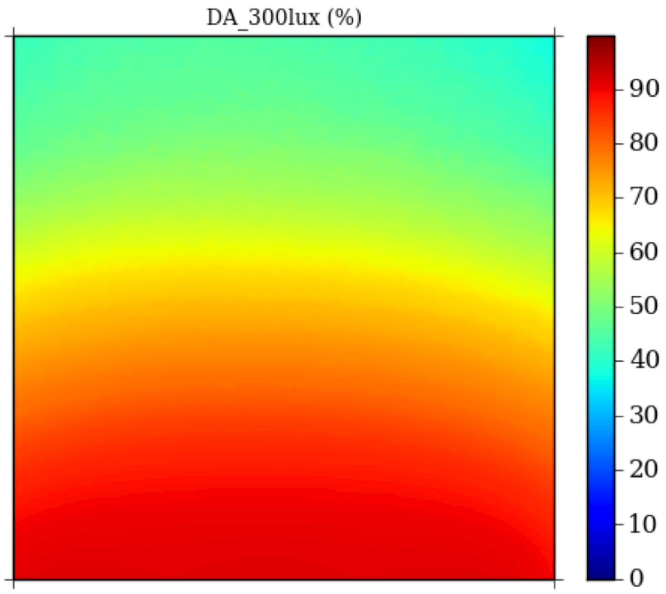


Figure 25: Daylight autonomy values for double clear glass with Fener

DOUBLE CLEAR GLASS WITH VERTICAL BLINDS (JK_ClearGlass_T70_emis2_0.077_VBlinds.xml)

Daylight factor

Max: 6.53 %
Mean: 2.13 %
Min: 0.52 %

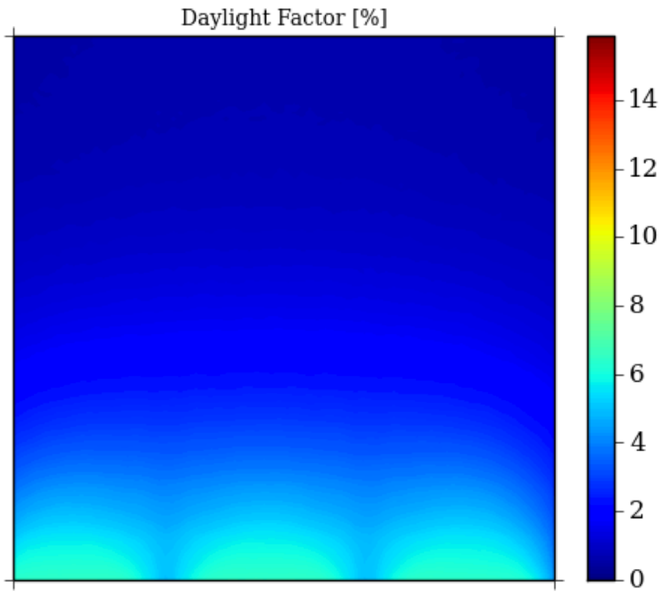


Figure 26: Daylight factor values for double clear glass with vertical blinds with Fener

Daylight Autonomy

$\mathrm{sDA}_{300,50\%}$ = 55.01 %
(July and Aug not considered)

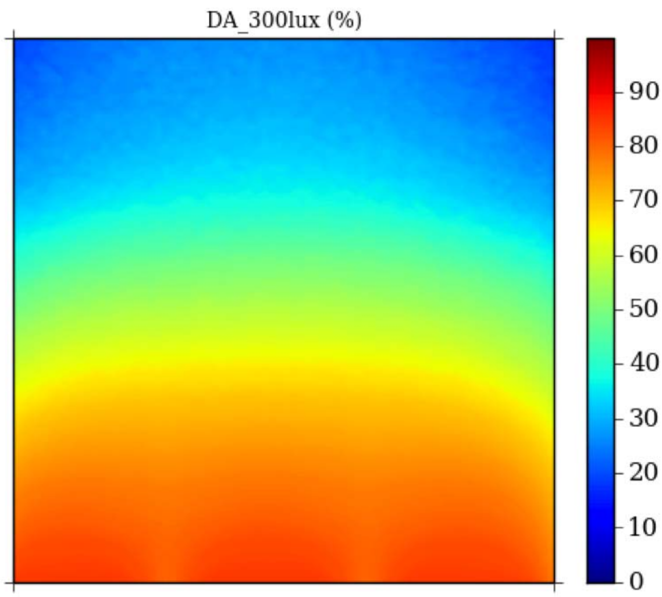


Figure 27: Daylight autonomy values for double clear glass with vertical blinds with Fener

DOUBLE CLEAR GLASS WITH DIFFUSE BLINDS (JK_ClearGlass_T70_emis2_0.077_DiffBlinds_ext.xml)

Daylight factor

Max: 2.04 %
Mean: 0.95 %
Min: 0.42 %

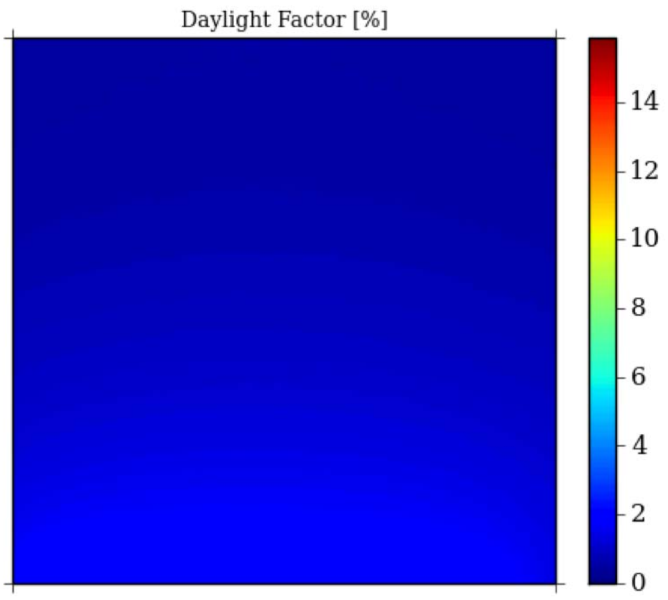


Figure 28: Daylight factor values for double clear glass with diffuse blinds with Fener

Daylight Autonomy

$\mathrm{sDA}_{300,50\%}$ = 50.76 %
(July and Aug not considered)

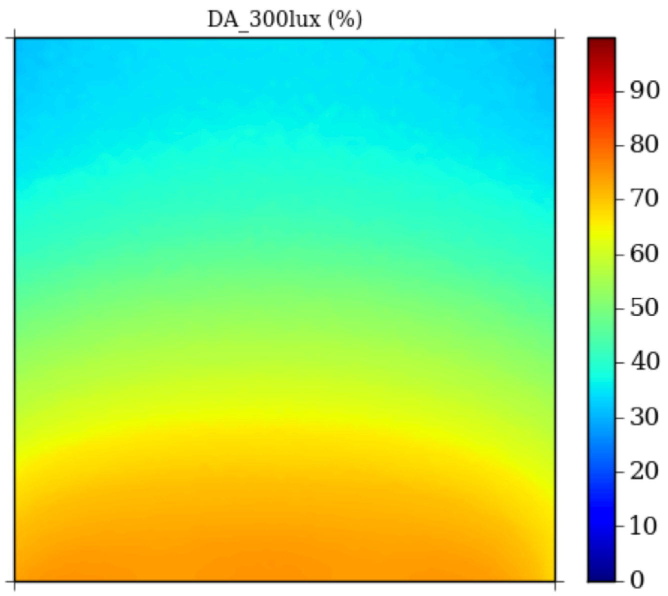


Figure 29: Daylight autonomy values for double clear glass with diffuse blinds with Fener

LASERCUT PANEL (Lasercut_Panel_145x1297.xml)

Daylight factor

Max: 9.99 %
Mean: 3.82 %
Min: 1.18 %

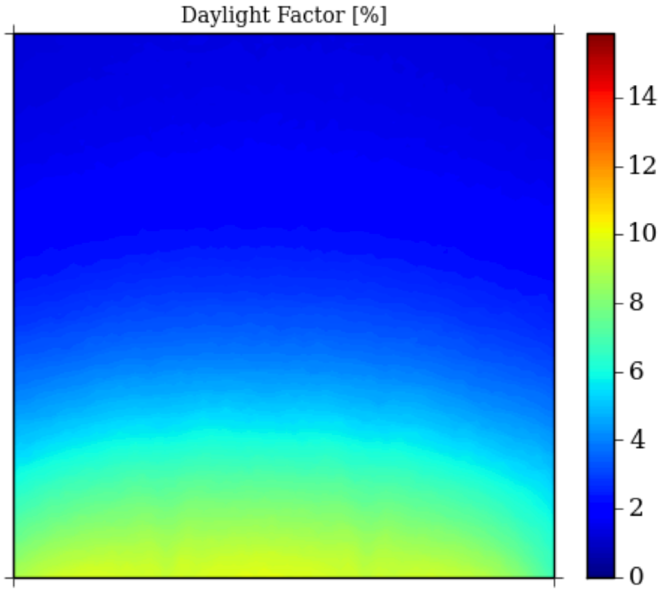


Figure 30: Daylight factor values for lasercut panel with Fener

Daylight Autonomy

$\mathrm{sDA}_{300,50\%}$ = 99.83 % (July and Aug not considered)

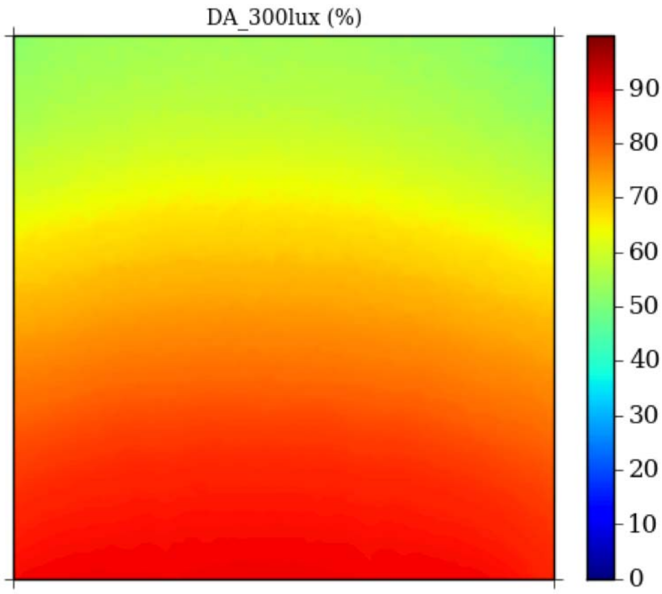


Figure 31: Daylight autonomy values for lasercut panel with Fener

3.2.3. Results from GERONIMO

Source: J. Kaempf / EPFL, LESO-PB, Switzerland

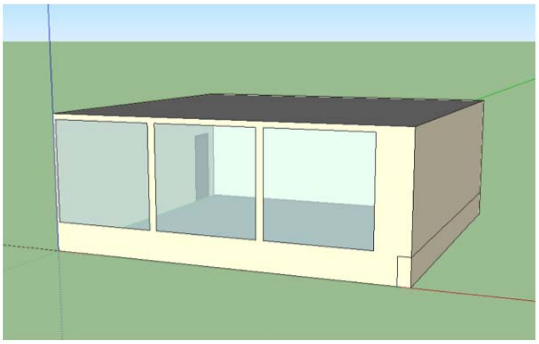


Figure 32: 3D-model in Sketchup: refurbished situation

DOUBLE CLEAR GLASS (JK_ClearGlass_T70_emis2_0.077.xml)

Daylight factor

Max: 16.3%
Mean: 5.2%
Min: 1.6%

Rendering

Figure 33: Daylight factor values and rendering for double clear glass with Geronimo

DOUBLE CLEAR GLASS WITH DIFFUSE BLINDS (JK_ClearGlass_T70_emis2_0.077_DiffBlinds_ext.xml)

Daylight factor

Max: 4.5%
Mean: 1.6%
Min: 0.6%

Rendering

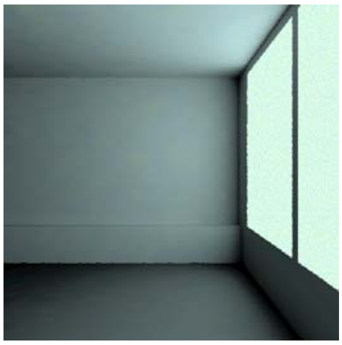


Figure 34: Daylight factor values and rendering for double clear glass with diffuse blinds with Geronimo

DOUBLE CLEAR GLASS WITH VERTICAL BLINDS (JK_ClearGlass_T70_emis2_0.077_VBlinds.xml)

Daylight factor

Max: 7.6%
Mean: 2.7%
Min: 0.9%

Rendering

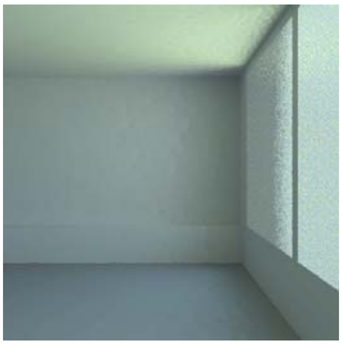


Figure 35: Daylight factor values and rendering for double clear glass with vertical blinds with Geronimo

LASERCUT PANEL (Lasercut_Panel_145x1297.xml)

Daylight factor

Max: 11.5%
Mean: 5.1%
Min: 2.0%

Rendering

Figure 36: Daylight factor values and rendering for laser cut panel with Geronimo

3.2.4. Results from Radiance

Source: D. Geisler-Moroder / Bartenbach GmbH, Austria

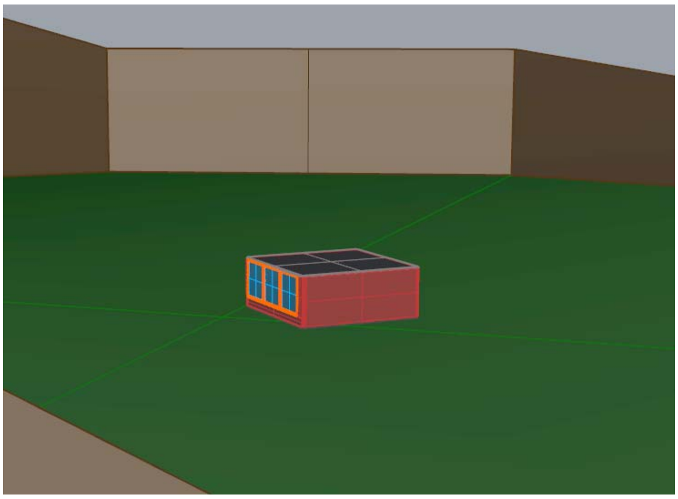


Figure 37: 3D-model in Rhino: refurbished situation

DOUBLE CLEAR GLASS (JK_ClearGlass_T70_emis2_0.077.xml)

Daylight factor
Max: ***12.96%***
Mean: ***3.04%***
Min: ***0.57%***
g1 (min/m): 0.19

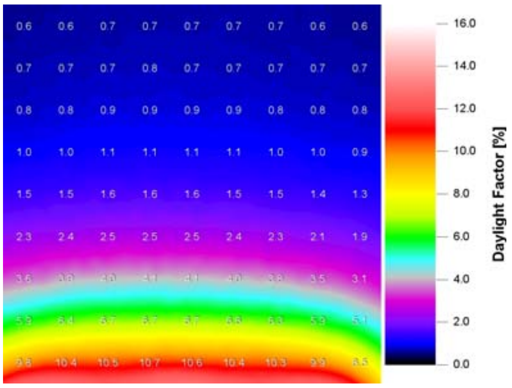


Figure 38: Daylight factor values for double clear glass simulated with Radiance

Daylight autonomy (DA 300lx, sDA)

- sDA300,50% = 55.3%
  (July and August not considered)
- “classical sDA”, i.e. all year, working hours 8am – 6pm:
  sDA300,50% = 63.5%

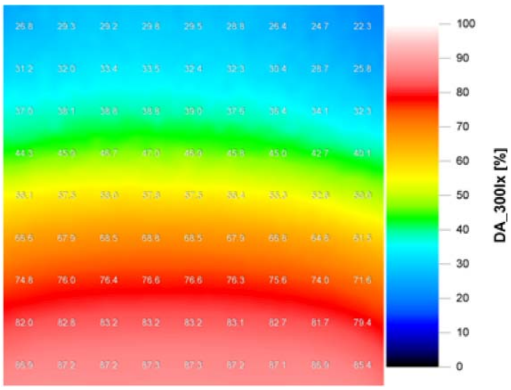


Figure 39: Spatial daylight autonomy values and falsecolor distribution of daylight autonomy for double clear glass simulated with Radiance

Rendering

Figure 40: Daylight distribution for double clear glass rendered with Radiance

DOUBLE CLEAR GLASS WITH DIFFUSE ROLLER BLINDS (JK_ClearGlass_T70_emis2_0.077_DiffBlinds_ext.xml)

Daylight factor

Max: 2.90%
Mean: 1.15%
Min: 0.50%
g1 (min/m): 0.43

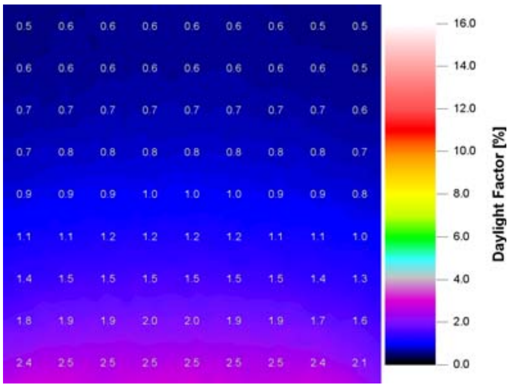


Figure 41: Daylight factor values for double clear glass with diffuse roller blinds simulated with Radiance

Daylighting autonomy (DA 300lx, sDA)

- sDA300,50% = 34.8%
  (July and August not considered)
- “classical sDA”, i.e. all year, working hours 8am – 6pm:
  sDA300,50% = 42.7%

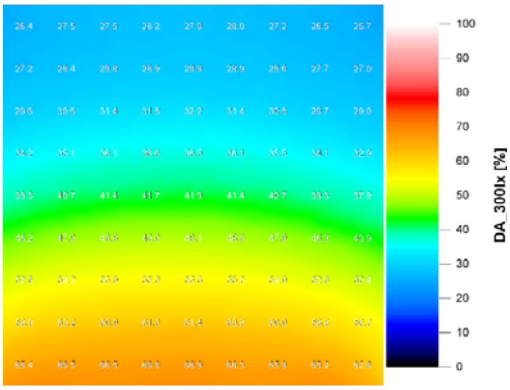


Figure 42: Spatial daylight autonomy values and falsecolor distribution of daylight autonomy for double clear glass with diffuse roller blinds simulated with Radiance

Rendering

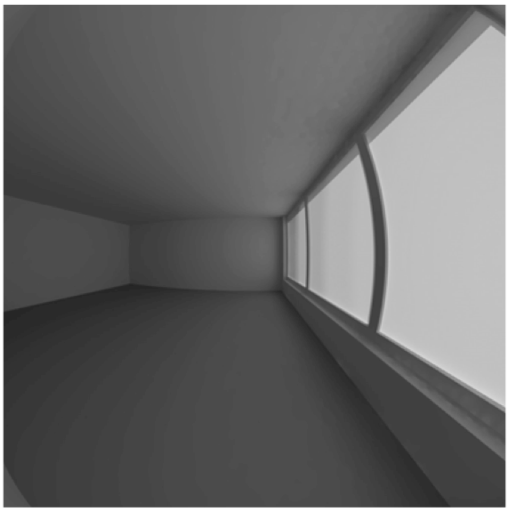


Figure 43: Daylight distribution for double clear glass with diffuse roller blinds rendered with Radiance

DOUBLE CLEAR GLASS WITH VERTICAL BLINDS (JK_ClearGlass_T70_emis2_0.077_VBlinds.xml)

Daylight factor

Max: 5.95%
Mean: 1.60%
Min: 0.35%
g1 (min/m): 0.22

Daylighting autonomy (DA 300lx, sDA)

- sDA300,50% = 40.2%
  (July and August not considered)
- “classical sDA”, i.e. all year, working hours 8am – 6pm:
  sDA300,50% = 45.4%

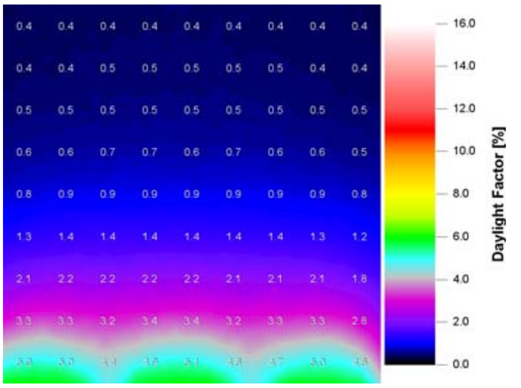


Figure 44: Daylight factor values for double clear glass with vertical blinds simulated with Radiance

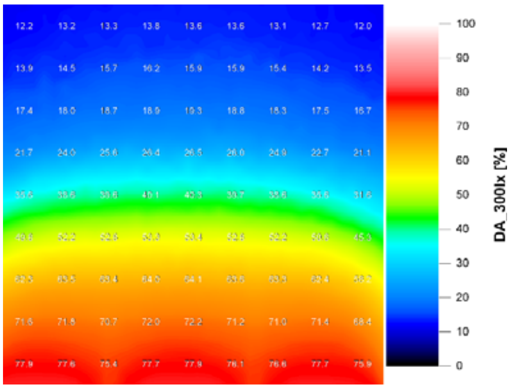


Figure 45: Spatial daylight autonomy values and falsecolor distribution of daylight autonomy for double clear glass with vertical blinds simulated with Radiance

Rendering

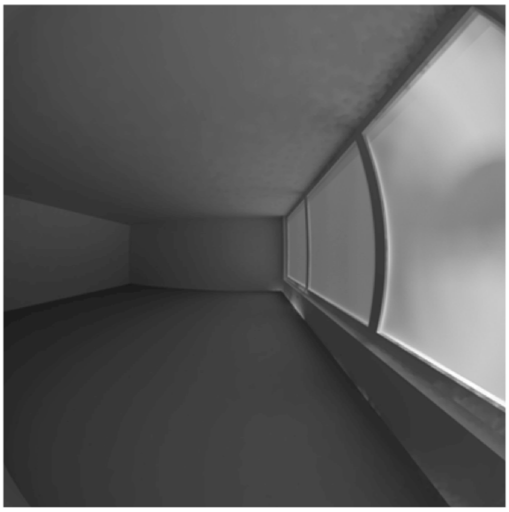


Figure 46: Daylight distribution for double clear glass with vertical blinds rendered with Radiance

LASERCUT PANEL (Lasercut_Panel_145x1297.xml)

Daylight factor

Max: 7.73%
Mean: 2.76%
Min: 0.73%
g1 (min/m): 0.27

Daylighting autonomy (DA 300lx, sDA)

- sDA300,50% = 72.5%
  (July and August not considered)
- "classical sDA", i.e. all year, working hours 8am – 6pm:
  sDA300,50% = 92.8%

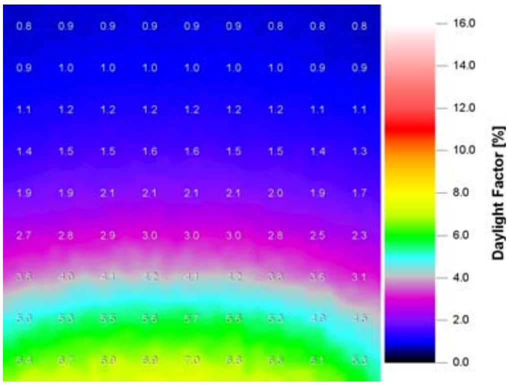


Figure 47: Daylight factor values for lasercut panel simulated with Radiance

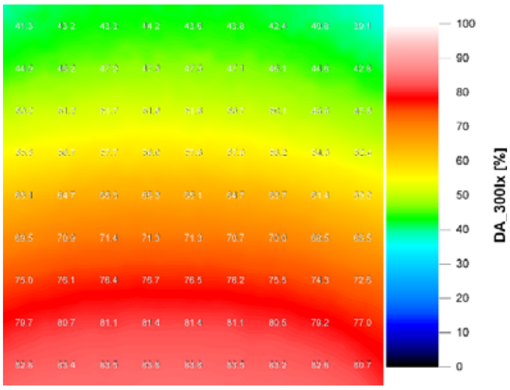


Figure 48: Spatial daylight autonomy values and falsecolor distribution of daylight autonomy for lasercut panel simulated with Radiance

Rendering

Figure 49: Daylight distribution for lasercut panel rendered with Radiance

3.2.5. Relux Pro

Source: J. Kämpf, LESO-PB / EPFL, Switzerland

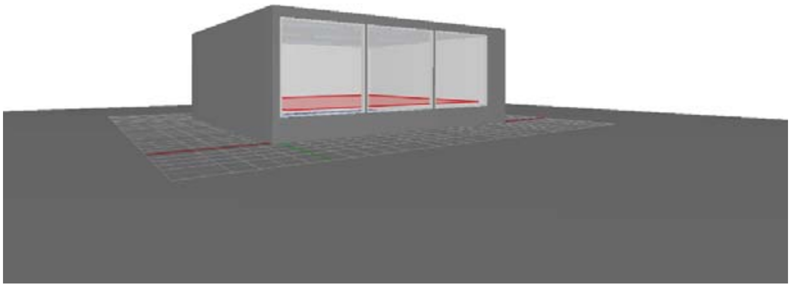


Figure 50: 3D-model in ReluxPro

Within our set of four CFS, only the Laser Cut Panel is available in the ReluxPro database.

LASERCUT PANEL (Lasercut_Panel_145x1297.xml)

Daylight factor

Max: 11.5%
Mean: 4.5%
Min: 1.5%
g1 (min/m): 0.33

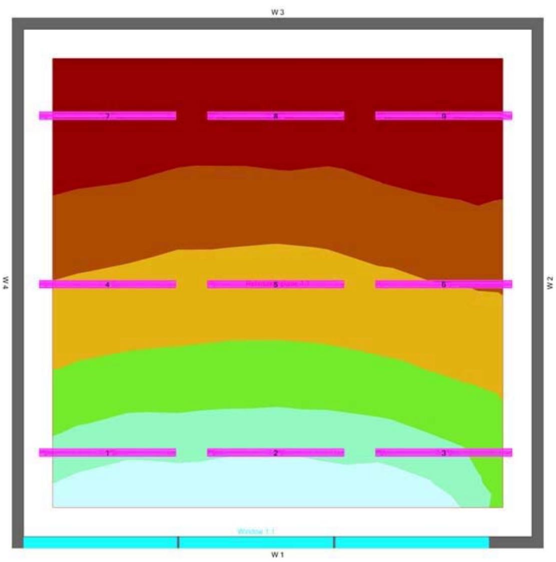


Figure 51: Daylight factor using contour lines

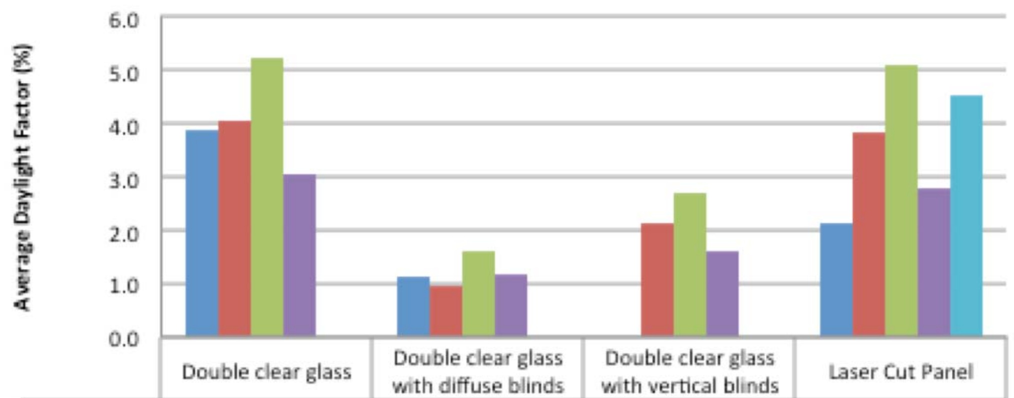
Rendering (with ray-tracing)

Figure 52: Ray-tracing engine rendering for laser cut panel with Relux Pro

3.2.6. Analysis of the results

Source: Jérôme Kämpf, Bernard Paule

Figure 53 illustrates graphically the results obtained with the different tools on the four fenestration systems tested. The discrepancies are rather large between the different tools with a maximum for Geronimo for all fenestration systems. This result may be explained by the simplicity of the 3D model employed for the simulations, indeed looking at the renderings for the clear sky conditions, one can notice that the model used by Geronimo does not include the wall thickness. Furthermore, even with similar simulation engines (RADIANCE for example), the rendering parameters play an important role, which may also lead to discrepancies. Due to the multiplicity of the potential error sources (including the ones from the users of the tool), a final conclusion is hard to draw on the results, excepting that the comparison between the different fenestration systems with any tool tend towards the same conclusion on their relative performance.



	Double clear glass	Double clear glass with diffuse blinds	Double clear glass with vertical blinds	Laser Cut Panel
DIALux evo	3.9	1.1		2.1
FENER	4.1	1.0	2.1	3.8
Geronimo	5.2	1.6	2.7	5.1
Radiance	3.0	1.2	1.6	2.8
ReluxPro				4.5

Figure 53: Average Daylight Factor values obtained with the different advanced simulation tools on 4 different complex fenestration systems described by Window XML files

The renderings show two main things:

- The clear glass does not represent all the details of the solar patches on the floor as it should in reality,
- The redirecting features of the Lasercut panel are well represented by distributing light towards the ceiling of the refurbished room.

The first one represents a limit in the actual simulations using BSDF data. The quality of the rendering depends on the resolution of the BSDF itself, which, in the cases of clear glass, clear glass with diffusive blinds and clear glass with vertical blinds is only of 145 by 145, following the Klems subdivision of the hemisphere (from Window software). In the case of

the Lasercut panel the resolution is higher in the output directions (every 5° by 5°) but not in the incoming directions with only 145 patches.
The second one gives an indication of the light distribution in the room, which is satisfactory enough to get an idea of illuminance profiles.

In order to analyze the discrepancies within the different simulation tools, box-plots were realized with the different daylight factor values obtained (Figures 57 to 60). Significant differences were found for the tested CFS likewise for the case study within C2.

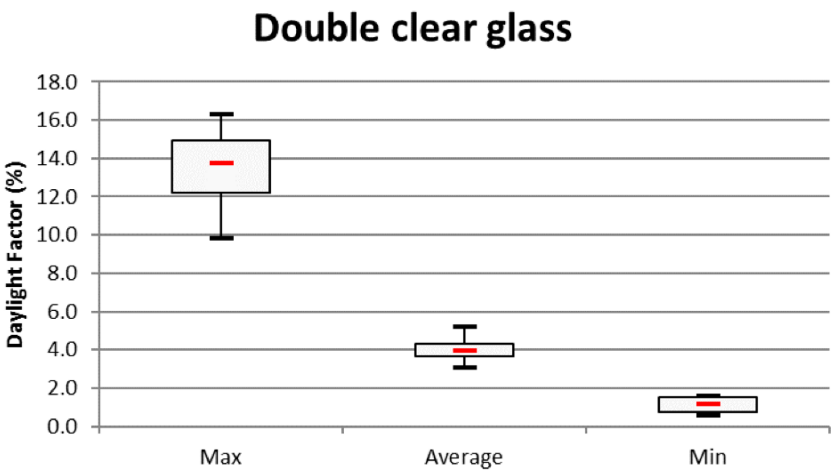


Figure 54: Distribution of the daylight factor for double clear glass

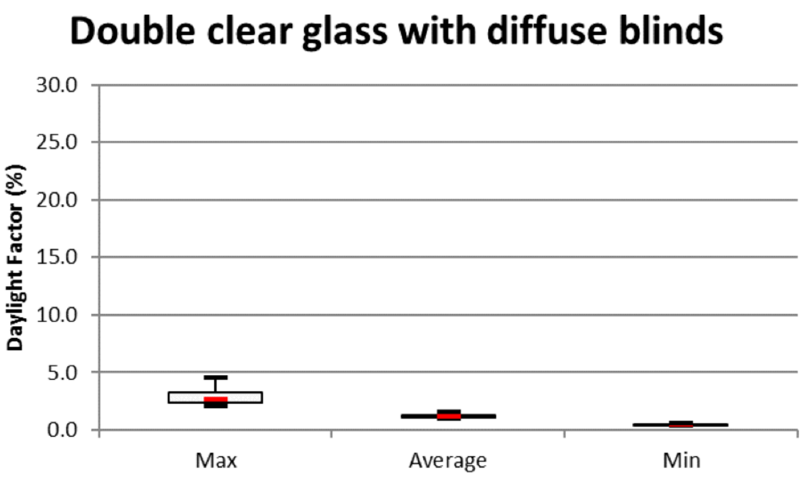


Figure 55: Distribution of the daylight factor for the double clear glass with diffuse blinds

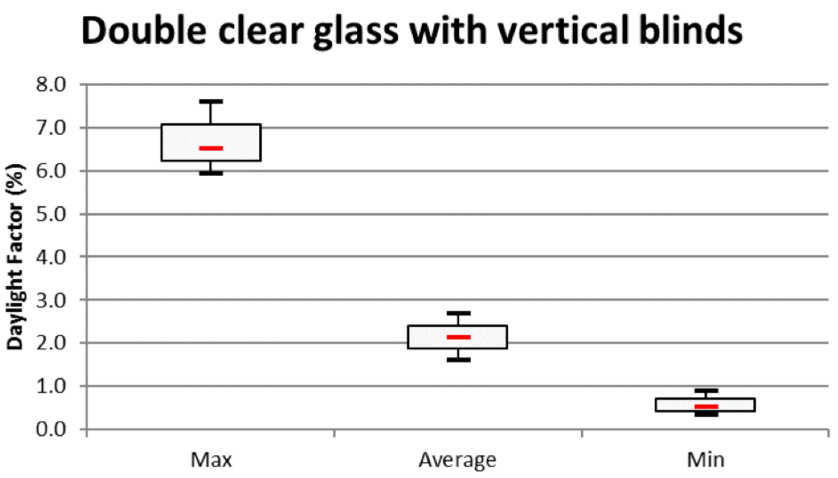


Figure 56: Distribution of the daylight factor for double clear glass with vertical blinds

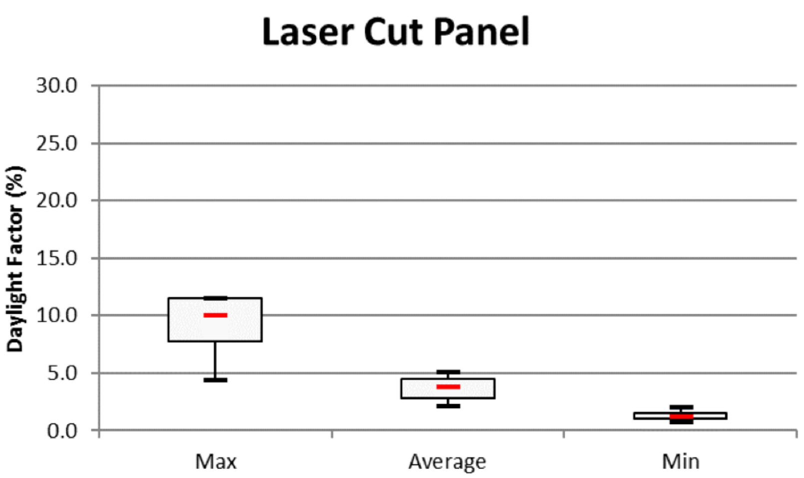


Figure 57: Distribution of the daylight factor for laser cut panel

4. Future and on-going developments

Future developments may include spectral sky models, which could be included in a sky model generator for RADIANCE and used in conjunction with the available spectral BSDF for coloured renderings. Furthermore, the DALEC online evaluation tool will shortly be available for practitioners.

4.1. DALEC

Source: D. Geisler Moroder / Bartenbach GmbH, Aldrans, Austria

www.dalec.net

DALEC (Day- and Artificial Light with Energy Calculation) is an online concept evaluation tool for architects, building engineers, lighting designers and building owners. Although easy to use and short calculation times, the software accounts for the complex thermal and light processes in buildings and allows a simple evaluation of heating, cooling and electric lighting loads. Location and orientation of the facade, climate data, thermal and photometric properties of the room, different shading and electric lighting systems are taken into account in the calculation.

Not only energy, but also user behaviour is considered (e.g. in terms of overheating and glare protection) and visual and thermal comfort is evaluated. This innovative, holistic approach facilitates and accelerates the design of sustainable and energy-efficient buildings for new structures as well as for refurbishments. The energetic optimization of façade and electric lighting solutions is highly simplified, enabling building design with reduced energy demands.

The motivation behind the development of DALEC is to simplify the handling of the complexity coming along with the interaction of the thermal and lighting energy performance aspects. Furthermore the simulation time must be less than a few seconds to allow optimizations of different façade situations. To realize that, the sophisticated lighting simulation components are pre-calculated for the most common room setups. As an example the daylight module is responsible for the calculation of the annual daylighting levels of the analysed room. An adapted and simplified daylight coefficient approach is used, which has been derived from the daylight coefficient model for dynamic daylighting simulations. To allow the usage of complex fenestration systems and to enable an efficient pre-calculation of the factors, the “Three-Phase Method based on the validated simulation software RADIANCE is used.

With this approach no simulation expertise is necessary for the tool user and calculation times are very fast. This allows optimisations of the façade settings, the artificial lighting installation and the thermal parameters of a building in an early design phase. It is not intended that DALEC replaces the existing, sophisticated energy and lighting simulation tools, but it will allow an accurate estimation of the influence of different façade setups on the electric lighting installation and different control strategies.

The software DALEC has been developed in a cooperation between the companies Bartenbach GmbH and Zumtobel Lighting GmbH together with the University of Innsbruck within the framework of a multi-annual scientific project funded by the Austrian Research Funding Society FFG. Further information about DALEC can be found at www.dalec.net or in

(Werner et al., "DALEC – A Novel Web-Tool for Integrated Day- and Artificial Light & Energy Calculation", submitted to J. Building Performance Simulation).

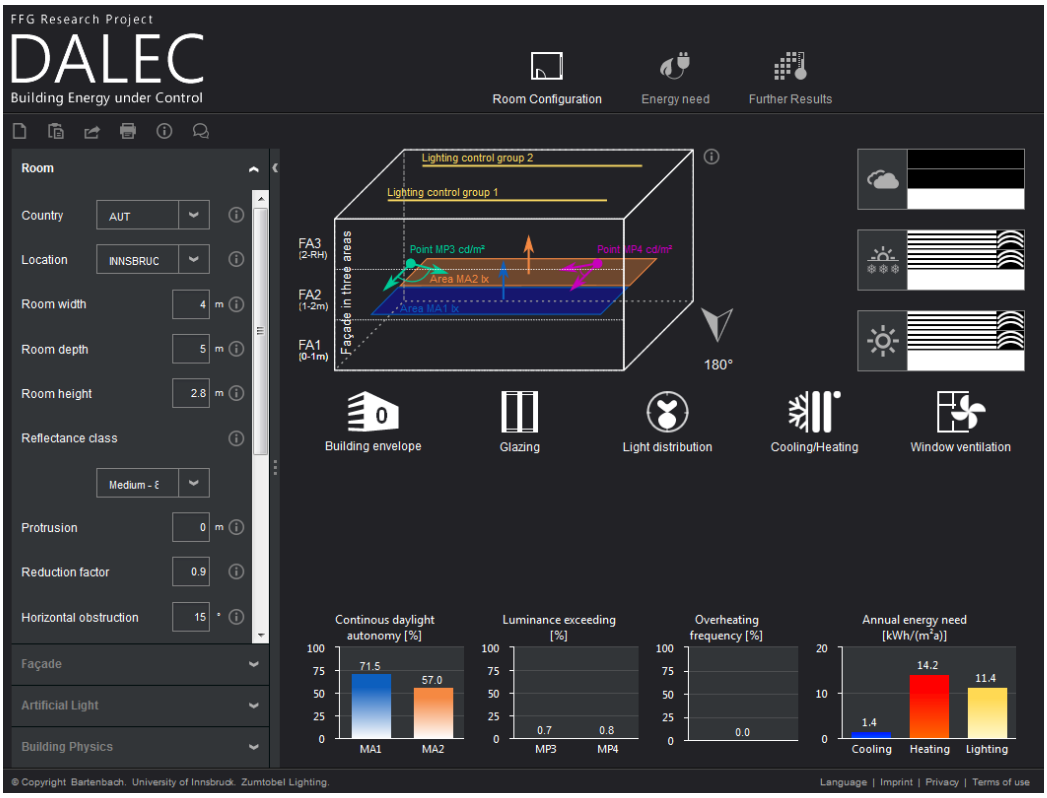


Figure 58: DALEC user interface

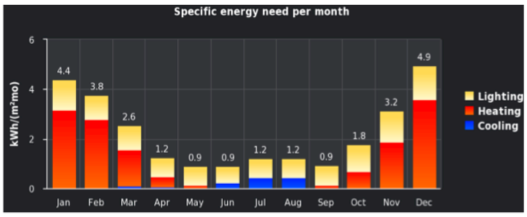


Figure 59: Resulting monthly energy needs for lighting, heating and cooling

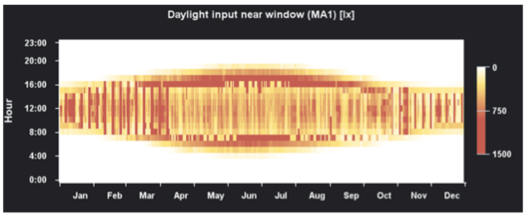


Figure 60: Annual chart showing the availability of daylight at the workplane next to the façade