SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Methods and tools for lighting retrofits
State of the art review

T50.C2

A Technical Report of IEA SHC Task 50

Advanced Lighting Solutions for Retrofitting Buildings

April 6th, 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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- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52)
- Solar Thermal & PV (Tasks 16, 35)
- Daylighting/Lighting (Tasks 21, 31, 50)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
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- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42)

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A Technical Report of Subtask T50-C2

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 Many countries face the same situation: The majority of the lighting installations are considered to be out of date (older than 25 years).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

This document proposes a state-of-the art review of the existing method and tools available on the market for practitioners. As starting point, the most used software were taken from the survey realised within C1, and those were categorised in four categories:

1) Facility management tools (global diagnostic tool including economic aspects)
2) Computer-assisted architectural drawing / Computer-aided design tools
3) Visualization tools
4) Simulation tools

The third category regarding the visualisation tools contains a warning for the practitioners, as they are not providing tangible results in terms of physical numbers. In total 20 software were described, and their main features compared in a table for a quick reference. Furthermore, the simulation tools were assessed using a case-study of a school refurbishment. Equivalent information given to practitioners was used to define the properties of the room (2D plans and photometric properties). Simulation experts were asked to simulate for daylight the daylight factor and for electric lighting the work plane illuminance. Results indicate a rather large dispersion for daylighting results between the different tools, even though the case-study was described with great care. However, on electric lighting the results remain within 10-15% range from the median value. The obtained results indicate that practitioners can rely on electric consumption computed by the tools during night time, but that the combination of daylight and electric light remains a challenge for simulation tools.

EXECUTIVE SUMMARY

Methods and tools for lighting retrofits of buildings should fulfil the needs of architects and lighting designers, which are focused on “lighting solutions”; it should also fulfil those of building services engineers, which are centred on “problem solving”. Both approaches should contribute in an efficient way to:

- Support the users for the description of the lighting retrofit project;
- Allow performance assessments of alternative retrofitting solutions;
- Promote the choice of optimal retrofitting solutions;
- Use the appropriate metrics for lighting, visual comfort and energy performance assessments.

In order to assist the practitioners in the choice of an appropriate method and tool for their specific need, a state-of-the-art review of the existing simplified methods and advanced simulation tools was carried out. The following categories together with the available method and tools for practitioners were identified and described:

- Facility management tools (global diagnostic tool including economic aspects): Epiqr+, Lotse Energieeffiziente Innenbeleuchtung, Optomiser, reLight
- Computer-assisted architectural drawing / Computer-aided design tools: 3DSMaxDesign, Autodesk Autocad, Rhinoceros, Sketchup
- Visualization tools:
  No description of the tools in this category was set-up as practitioners should rather use simulation tools
- Simulation tools:
  Daysim, Dialux, Dialux-Evo, Dial+Lighting, Diva-for-Rhino, Fener, Geronimo, Ies-Ve, Lightsolve, Radiance, ReluxPro, Velux Daylight Visualizer

A global scheme for the comparison of the features of the described method and tools was further proposed to quickly assess their potentialities using a simple table (p. 58). Furthermore, the primary results (daylight factor) of the simulation tools on a refurbishment case study were assessed and compared. The case study consists of an existing classroom located in Switzerland that went recently through a lighting retrofit process. General information about the classroom is provided in order to allow its simulation by the lighting experts. Those consist in 2D plans and basic photometric information in order to mimic the real life situation of refurbishment processes for the practitioners. The case-study indicates the position and type of windows and luminaires in the original and the refurbished room in order to simulate daylight and electric lighting.
The dispersion between the results obtained with the different simulation tools is rather large for daylighting, indeed even though the case-study was described with great care and handled by lighting experts. This indicates that the end-users of such tools should not rely at 100 % on the simulation results for daylighting. However, the dispersion on the electric lighting illuminance results exhibits a reasonable accuracy within 10-15%, indicating that electrical consumption calculations based only on electric lighting are more reliable than the ones relying on a combination of daylight and electric light.

Table of Contents

1. INTRODUCTION

Methods and tools for lighting retrofits of buildings should fulfill the needs of architects and lighting designers, which are focused on “lighting solutions”; it should also fulfill those of building services engineers, which are centered on “problem solving”. Both approaches should contribute in an efficient way to:

- Support the users for the description of the lighting retrofit project;
- Allow performance assessments of alternative retrofitting solutions;
- Promote the choice of optimal retrofitting solutions;
- Use the appropriate metrics for lighting, visual comfort and energy performance assessments.

The number of simplified methods and advanced simulation tools allowing the evaluation of lighting and visual comfort metrics is currently large. Some of them can be applied both to daylighting and electric lighting allowing an integrated approach for lighting retrofit procedures. Some others can perform daylighting and energy calculations allowing the assessment of energy efficient solutions. Certain methods have achieved a significant success in the building sector: ray-tracing techniques combined with daylight coefficient calculations allow the evaluation of annual lighting and energy performance for large building retrofit projects on a simple PC computer.

In this document, a state-of-the-art review of the existing simplified methods and advanced simulation tools was carried out. We distinguished the four following categories of tools:

- Facility management tools
- CAAD / CAD tools
- Visualization tools
- Simulation tools

Each tool was described either by one of the experts involved in this IEA-50 task or by an external consultant if needed. The list of tools presented here is not exhaustive. We decided to describe the tools that were mentioned at least twice in the survey (section C1) and which are available for day-to-day retrofitting practices. Some of these tools integrate advanced capabilities such as possibility to handle complex fenestration systems and that are still under research and development. These capabilities are described in detail in C5 section.

The report is organized as follows:

- Description of the selected tools for each category
- Scheme of comparison for the simulation tools (matrix)
- Comparison of the results obtained with the simulation tools.

This report is intended for practitioners seeking information on the main tools available on the market. It may also be useful for developers to compare the specifications between their respective tools.

Beyond the description of tools, this document also puts into perspective the results that they allow us to obtain. In particular, the comparative analysis of the results obtained with the case study shows that simulation is not an “exact science”. A point to note is that simulation tools should not be used to make ex-post analysis of a given solution, but to guide the design process by evaluating different alternatives in the early stages.

Disclaimer: several contributors provided the description of the different tools, IEA cannot be held responsible for unreliable or incorrect information.

2. FACILITY MANAGEMENT TOOLS (global diagnostic tools including economic aspects)

2.1. EPIQR+

Source: B. Paule / Estia SA, Switzerland

Supplier, site, contact, last version, cost

Estia SA (CH), Calcon AG (D)
http://www.estia.ch/index.php?id=242&L=6_%27
www.epiqr.ch
www.epiqr.com
Contact: Dr Flourentzos Flourentzou (*mail@estia.ch*)

Functions

EPIQR+ is the last version of a software based on the EPIQR method that was developed between 1996 and 1998 within the framework of the JOULE II European research program and was supported by the Swiss Federal Office for Education and Science.

The goal of this tool is to help experts to make a systematic diagnosis of existing buildings, in order to estimate the state of degradation and to elaborate refurbishment scenarios. Outputs include a list of works and actions with the associated costs and the resulting energy consumption.

The software allows to:

- Establish a complete record of information allowing describing the general state of the building to be renovated,
- Elaborate a diagnosis on the physical and functional condition of the building,
- Determine in detail the nature of the works required,
- Estimate the likely amount (± 15%) corresponding to the restoration of the building,
- Optimizes the energy consumption of the building after refurbishment,
- Take the necessary accommodation measures dealing with the correction of disorders related to air quality and interior comfort
- Compare intervention scenarios taking into account the aging of building elements and the evolution of costs according to the work planning (investment planning).
- Explore the possibilities of increasing the building use value (after refurbishment).

Description procedure

The principle is to make a complete inspection of the building, following a systematic path, which allows reviewing its entirety (visual observation, without destructive sampling or specialist consultation).

To establish the diagnosis of physical and functional degradation as well as the estimated cost of the refurbishment works, the building is divided into 29 macro-units that correspond to groups or chains of components that perform the same function unit. Each macro-unit includes detailed elements (>500 elements in total) corresponding to components of the building.

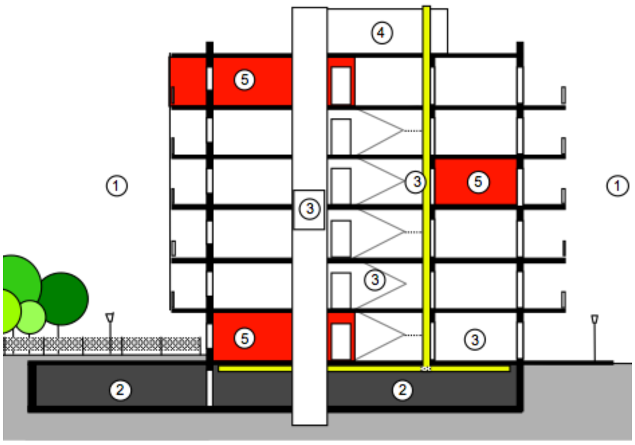


Figure 1: EPIQR standardized visit path
1. Inspection of outdoor spaces and facades
2. Inspection of basements
3. Inspection of stairs and common premises
4. Inspection of attic and roof
5. Inspection of at least 3 housings units

29 macro-units, 500 elements

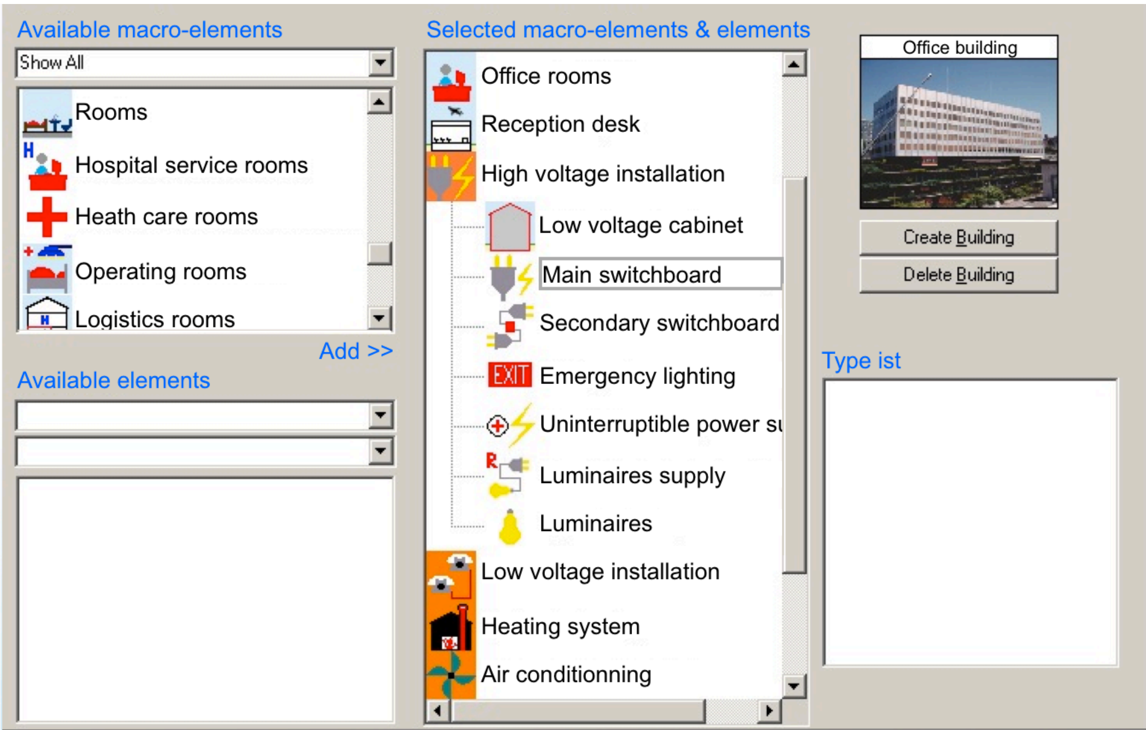


Figure 2 : Example of the macro elements and components available in EPIQR

Types
In order to apply the method to any buildings, types have been defined for some elements. These types may depend on the age of the building, the constructive system or the component itself.

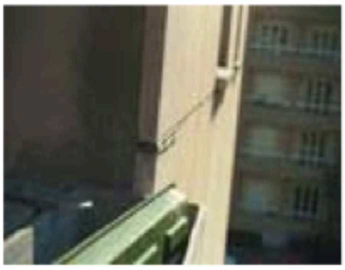
Ex. Element 03: "Facades". This element includes the 5 following types (see Figure 3):

- Parging
- Exposed masonry walls
- Precast concrete walling
- Decorative stone walls
- Curtain wall façades

Type 1 Parging

Type 2 Exposed masonry walls

Type 3 Precast concrete walling



Type 4 Decorative stone wall

Type 5 Curtain wall façade

Figure 3: Illustration of the notion of « Types » - here the façades

Four degradation statuses

Four degradation codes are used to assess the degree of degradation of each of the Elements. They represent the most likely physical or functional degradation corresponding to the given element.

Code A: Good condition: no comment, only regular maintenance must be performed (e.g. setting of the boiler burner, cleaning of luminaires, etc.).
Code B: Slight degradation: the function of the element is fully insured, early indications of wear appear, protection works or small repairs are possible and useful
Code C: Average degradation: the function of the element is still ensured in overall, but some elements observed are in poor condition and should be replaced as far as repairs are not easy. There may have ripple effects on other components.
Code D: End of life: performances are not insured. The item cannot be repaired; it must be replaced. There may be spill over effects on other components.

For some items, additional codes (S,T, U & b) correspond to interventions aiming to improve the level of performance (increased use value)

Code	**Status**	**Urgency**	**Works**
A	Good	To maintain	Maintenance
B	Slight degradations	Points to watch	Basic adaptation
C	Average degradations	Step in	Medium adaptation
D	End of life	Step in immediately	Replacement
S,T, U or V	Potential for improvement	Optional	Increase of use value

Table 1: Degradation codes and the links with urgency and works

Priority
Each of the codes corresponds to concrete work and is weighted by a priority level that is used to characterize its urgency.

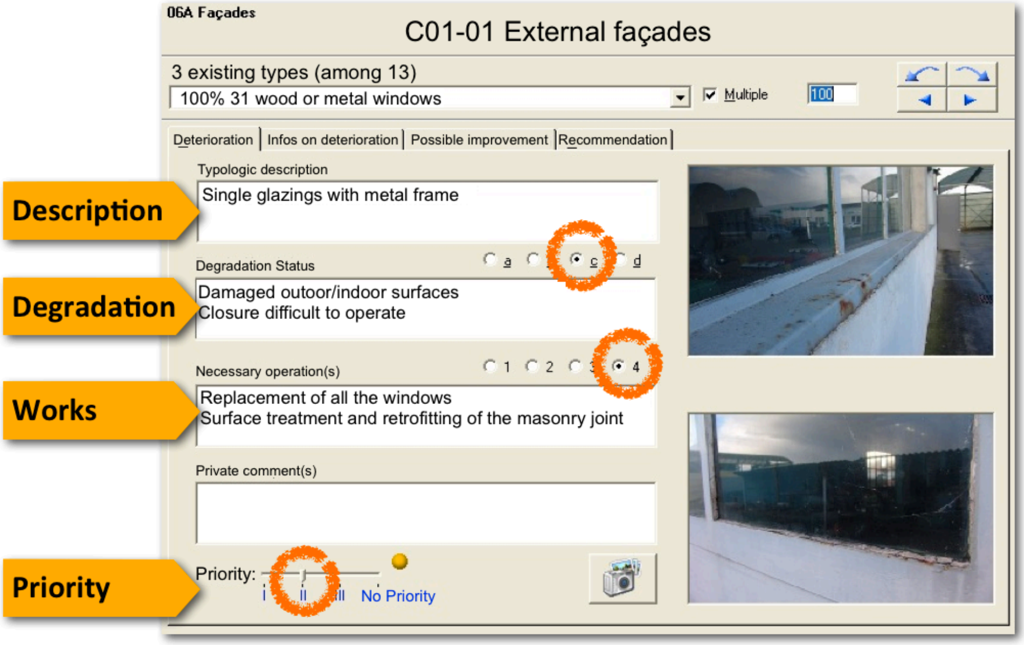


Figure 4: Description of the degradation status of a given element (here the windows)

Results

At the end of the process, EPIQR+ gives a global overview on the building status and offers the possibility to make evaluate the impact of various refurbishment scenarios. The cost and energy performance of each scenario allows the user to make a clear decision about the retrofitting process.

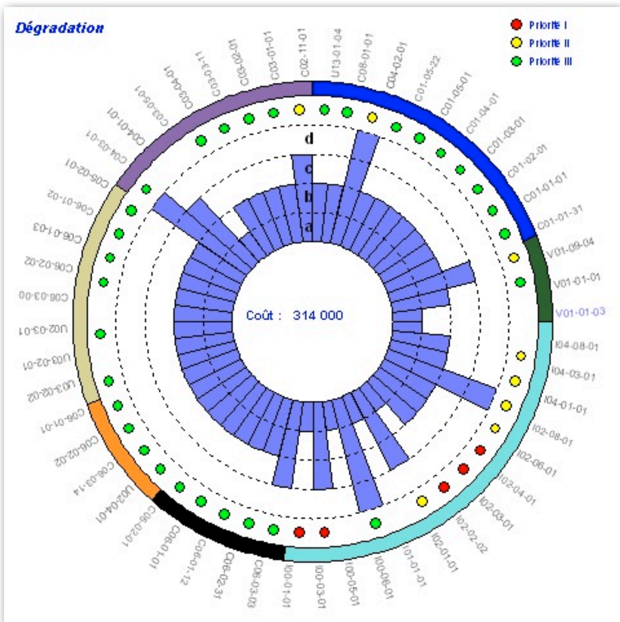


Figure 5: Overview of the degradation status of a given building: Long stripes indicate that the element is degraded and red circles refer to a high priority

References

http://www.epiqrplus.ch

2.2. LOTSE Energieeffiziente Innenbeleuchtung (Guide for energy efficient interior lighting)

Source: J. de Boer / Department Heat Technology, Fraunhofer Institute of Building Physics, Germany

Figure 6: Screenshots of the LOTSE interface © German Energy Agency (dena: Deutsche Energie Agentur)

Supplier, site, contact, last version, cost

The “Guide for energy efficient interior lighting” (Lotse energieeffiziente Innenbeleuchtung) was jointly developed by the German Energy Agency (dena, Deutsche Energieagentur) and the German Electrical and Electronic Manufacturers' Association (ZVEI, Zentralverband Elektrotechnik- und Elektronikindustrie e.V.).

This online-advisory-tool has been available since 2012. It is for free and can be found at: http://www.lotse-innenbeleuchtung.de/

Functions

With an easy to understand and to use interface, the “Guide for energy efficient interior lighting” (Lotse energieeffiziente Innenbeleuchtung) provides mainly informative directions on energy efficient retrofit of lighting systems. The information given depends on the target group selected and is organized in the phases of a typical retrofit process. In addition, a rough estimate on energy and CO2 saving potential is provided.

Description procedure

The information is organized in blocks to select, structured in the phases of a typical retrofit process: actual state analysis, planning, financing, procurement, and maintenance. The number, content and level of detail of these different blocks depend on the target group, which has to be selected by the user in a first step. Second, before entering the informative section, there is the option to run a so-called quick check. Based on a very simplified calculation procedure, an estimate of the energy saving potential is given, depending on the following inputs: type of the building (office, storage or production), size of the building, age of the lighting system, electricity costs and yearly operating hours.

References

http://www.lotse-innenbeleuchtung.de/

2.3. OPTOMIZER

Source: J. de Boer / Department Heat Technology, Fraunhofer Institute of Building Physics, Germany

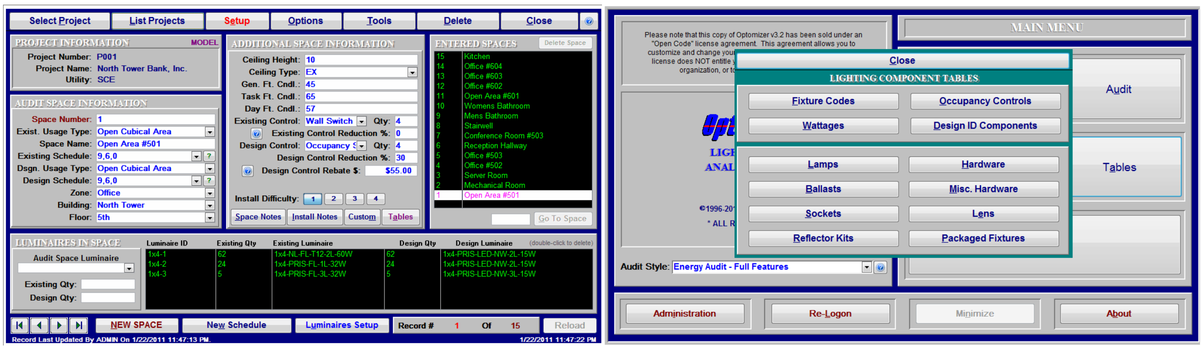


Figure 7: Screenshot of the OPTOMIZER interface © Fielding Data Labs

Supplier, site, contact, last version, cost

OptoMizer was developed by Fielding Data Labs. The last officially released version is v3.2. It is available via the Lab's website at costs of $499 USD. In its current version, the program runs with Microsoft Access 2007 or 2010.

http://www.fdlabs.com/products/optomizer.html

Beside an online-demonstration of the tool available at the website, it is also possible to download a demonstration version of the program. According to the information given on the website, "this evaluation download is the fully functional version of OptoMizer v3.2. The software comes pre-loaded with one sample 15-space lighting audit, and is limited to allowing data entry for up to 1 additional project with a maximum of 10 audit spaces for evaluation purposes." [http://www.fdlabs.com/demo/]

Functions

OptoMizer provides the tools necessary to perform a full, accurate and detailed lighting audit. The software supports an unlimited number of projects and audits, full physical parts tracking and pricing, existing and design luminaire configurations, occupancy schedules, and detailed space data to support space-by-space audits.

Detailed rebate program tracking is included to allow for energy savings or per-component style rebate programs. OptoMizer incorporates all of the lighting technology needed to create reports that range from detailed space-by-space energy savings analysis, to full project parts lists, carbon footprint analysis, and budget cost reports.
Source: OptoMizer Product Data Sheet, Fielding Data Labs

Description procedure

Within OptoMizer, Lighting Designers can create comprehensive part libraries, create detailed design fixtures, and tie those design fixtures to actual part components and budget costs. Lighting Auditors can then create existing fixtures as found on the site, and tie those existing fixtures to the design fixtures. With this sophistication, reports can then easily be generated to produce accurate energy savings, budget costs and complete parts lists for an overall audit.

Within OptoMizer, a single audit can be cloned into separate 'Model' and 'Construction' audits. Once the initial audit has been performed, and the data has been collected in OptoMizer, the lighting designer can preserve the original audit design as the 'Model' audit, and clone the entire 'Model audit to a 'Construction' Audit. As the actual lighting retrofit project takes place, the 'as-built' changes can be made to the 'Construction' audit. This allows the designer to easily run comparisons between the 'Model' and 'Construction' audits once the project is complete.

References

http://www.fdlabs.com/products/optomizer.html

2.4. reLight
An efficient tool for on-site inspection of lighting installations and identification of potentials

Source: J. de Boer / Department Heat Technology, Fraunhofer Institute of Building Physics, Germany

Figure 8: Screenshots of the RELIGHT application © Fraunhofer IBP

Supplier, site, contact, last version, cost

reLight - a tool for on-site inspection of lighting installations and identification of potentials was developed by the Fraunhofer Institute for Building Physics IBP under a grant by the German Federal Institute for Research on Building, Urban Affairs and Spatial Development with support from the industry. This mobile-inspection-tool is available since August 2013. It is for free and can be downloaded under: http://www.relightapp.de/

Functions

The aim of reLight is to make on sight inspection and analysis of existing lighting systems easier. It also offers other useful energy consultancy functions, such as creating cost comparisons over periods of time. An assessment of the existing lighting system is done by means of a visual comparison and a simple qualitative description of the room proportions and façade type. Within minutes this leads not only to an energy analysis of the existing lighting system, but at the same time to suitable renovation suggestions, including a separate statement on costs for the different proposals.

Description procedure

Pre-parameterization and verification logic ensure that no invalid data sets are created and that results can be viewed quickly. The app features a multi-zone model that enables to assess and manage whole buildings. When there are several rooms of the same kind, only one of them needs to be analysed This room serves as model for the others.. Depending on the user's interests and needs, different renovation options per zone can be combined into an overall renovation concept, in order to obtain optimum energy and/or cost-efficiency results for the building. These results can be viewed numerically and are also graphically depicted. relight runs on the Android operating system. Part of the underlying concepts logic have been used and further developed in the Lighting Retrofit Adviser of IEA-SHC Task 50.

References

http://www.relightapp.de/

3. CAAD / CAD TOOLS Computer-assisted architectural drawing / Computer-aided design

3.1. 3DSMaxDesign

Source: M. Bodart / Université catholique de Louvain (UCL) Faculté d'architecture, d'ingénierie architecturale, d'urbanisme (LOCI), Belgium

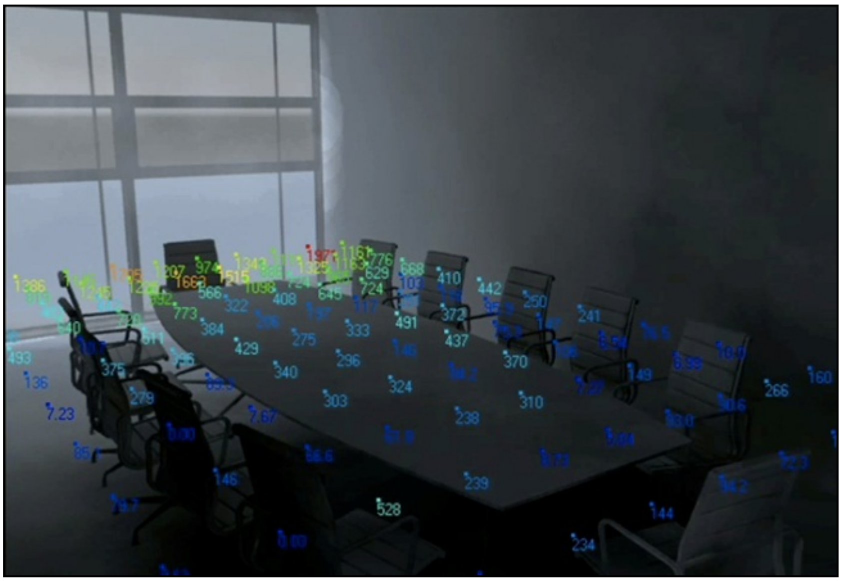


Figure 9: Example of the results obtained with 3DSMaxDesign (illuminance values)

Supplier, site, contact, last version, cost

3dsMaxDesign is developed and commercialized by Autodesk. The last version is 3dsMaxDesign 2015 and it cost $ 3675
All the information can be found on the following website:
http://www.autodesk.com/products/3ds-max-design/overview

CAUTION: Be sure to buy the 3dsMax design and not 3dsMax as the latter does not allow lighting simulations.

Functions

The 3dsMax software is developed by Autodesk and is a comprehensive 3D design tool. Since 2009, 3dsMAxDesign is proposed by Autodesk. Both version of the software share the same technology and have the same key functionalities.

While 3dsMax is mainly used by video games developers and TV studios, 3dsMaxDesign is more adapted to architects, designers and engineers. It allows making accurate daylight and electric light simulations, for static conditions, under CIE overcast and clear sky conditions. The integration of the Perez Model also allows the user to evaluate his model on basis on weather data files (dynamic simulations). Light animation can also be done from these simulations.

Lighting analysis in 3dsMaxDesign 2009 is based on the mental ray® rendering engine, using the ray tracing method. 3dsMaxDesign calculates the illuminance and luminance values and makes accurate rendering views.

For dynamic simulations, 3dsMaxDesign uses the EnergyPlus weather data files (.epw files), freely available on the US Department of Energy's EnergyPlus website, allowing the software to model daylighting conditions during all hours of the year. These files are available for more than 1000 locations in USA and more than 1000 locations in 100 other countries.

Design Stage, users

3dsMaxDesign is probably to be used at an advanced design stage as it can take time to make the geometry model, enter precise material information and the design sky. User should follow an accurate process in order to be able to calculate accurate results.

3dsMax Design should be reserved to lighting specialists, as the results require to be analysed with a critical eye. Indeed, some bugs exist in the software who sometimes lead to very surprising results (i.e. daylight factors higher than 100 % in 3dsMaxDesign 2013).

Import / Export

A lot of different format model can be imported in 3dsMaxDesign.
In 3dsMaxDesign 2013 : the following format are supported :
.FBX, .3DF, .PRJ, .AI, .APF, .ASM, .CATPART, .CGR, .CATPRODUCT, .DAE, .DEM, .XML, .DDF, .DWG, .DXF, .FLT, .HTR, .IGE, .IGES, IGS, .IPT, .IAM, .JT, .MODEL, .DLV4, .DLV, .EXP, .SESSION, .MDL, .OBJ, .PRT, .SAT, .SHP, .SKP, .STL, .STP, .STEP, .TRC, .WIRE, .XML.

Results of illuminance values (static): the simulations results on the lighting sensors (illuminances) can be exported in a .csv file that can then be imported into Excel.
Result of illuminance values (dynamic): the results can be exported as a csv files. This csv will contain, for each time step and sensor, the illuminance value. Dynamic metrics as daylight autonomy or UDI have to be calculated afterward.

For presentation purposes, the rendered images can be overlaid by light levels (numbers or falsecolor).

References

Christoph Reinhart, Marion Landry, Pierre-Felix Breton. Daylight Simulation in 3ds Max Design 2009 – Getting Started. In : images.autodesk.com/adsk/files/3dsmax_started.pdf. Access : September 2014.

3.2. AUTODESK AutoCAD

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

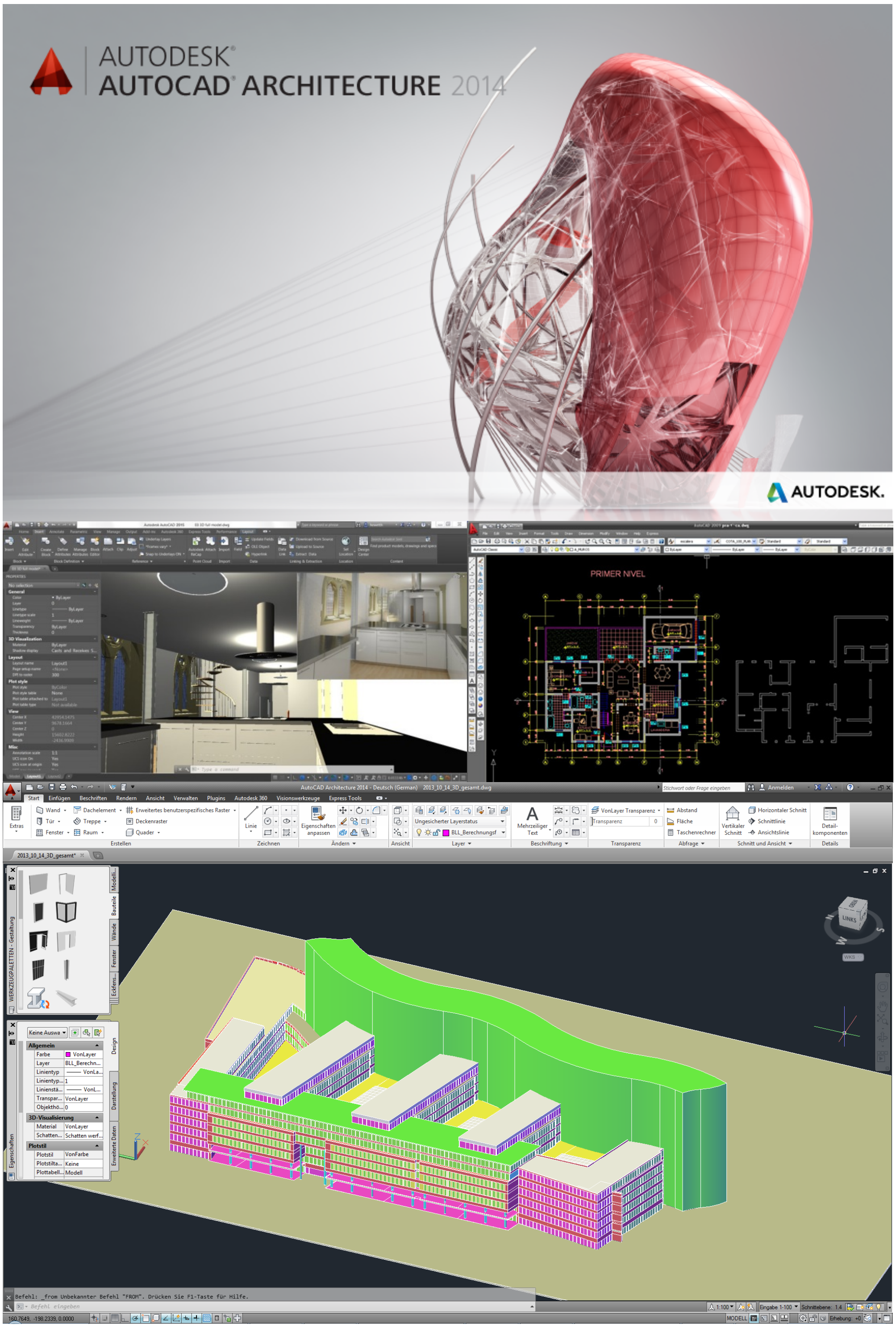


Figure 10: Screenshots of the AUTOCAD interface © www.autodesk.com

Supplier, site, contact, last version, cost

AUTODESK AutoCAD [http://www.autodesk.com/products/autodesk-autocad/] has been developed by AUTODESK. The latest official version is AUTOCAD 2015. There are four main AutoCAD products available: AutoCAD LT (professional 2D drafting and

documentation), AutoCAD (2D and 3D design), AutoCAD Design Suite (vectorization and visualization capabilities to create high quality renderings) and AutoCAD 360 which contains additional multi-device editing capabilities. Other products as AutoCAD Architecture, AutoCAD Electrical or AutoCAD Civil 3D extend AutoCAD functionality to specific fields
A rental license of AutoCAD 2015 is 300€ / month (265 USD) or 2390€ / year (2100 USD). The AutoCAD Design Suite standard 2015 costs 340€ / month (285 USD) or 2700€ / year (2265 USD). AutoCAD 2015 and the AutoCAD Design Suite standard 2015 can also be purchased for 4775€ and 5400€, respectively.

A large number of AutoCAD plugins is available in the application store Autodesk Exchange Apps [http://apps.exchange.autodesk.com/de]. The software is available for both Windows and Mac.

Functions

AutoCAD allows developing 2D and 3D vectorial drawings and creating 3D visualizations. High quality renderings can be created with the package AutoCAD Suite.
AutoCAD allows creating different typologies of 3D geometry which are: solid (i.e. full 3D elements), surfaces, polysurfaces and meshes as well as other simple 3D geometric elements as lines, curves and planes. It is also possible to convert 3D solids into mesh surfaces, which is useful to improve its compatibility with other tools.

Furthermore, AutoCAD supports APIs for customization and automation which include AutoLISP, Visual LISP, VBA, .NET and ObjectARX (a C++ class library).

The software is suitable to draw presentations by providing a layout space connected to the model space. With additional plugins it is possible to improve map modelling (adding geolocation, extracting isoline curves) or AutoCAD's capabilities in 3D free form design. It is also possible to connect the workflow across integrated desktop, cloud, and mobile solutions.

Design Stage, users

AutoCAD has been developed to be used at all stages of building design, from sketch and basic design models to advanced 3D modelling and executive design. It is used by architects, engineers and designers, allowing both to produce technical drawings and to develop building visualizations and renderings.

Results

Main benefits are the development and presentation of technical and executive 2D drawings, and the development of 3D models with medium level of complexity. There is a large variety of CAAD libraries containing objects and construction elements included in the software and available on the web.

Import / Export

AutoCAD can import files in .dwg, .dws, .dxf, .dgn, .ifc and .dwt format.
It is possible to export files in .dwg, .dwf, .dwfx, 3D dwf, PDF, DGN, IFC (industrial foundation classes), and gbXML (Green Building XML format). It is further possible to export property set data associated with AEC format and an MDB database. Other exportable formats are: .fbx, .wmf, .sat, .stl, .eps, .dxx, .bmp, .dgn, .iges, .igs, .dws, .dwt.

References

http://www.autodesk.com/products/autodesk-autocad/

3.3. Rhinoceros

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

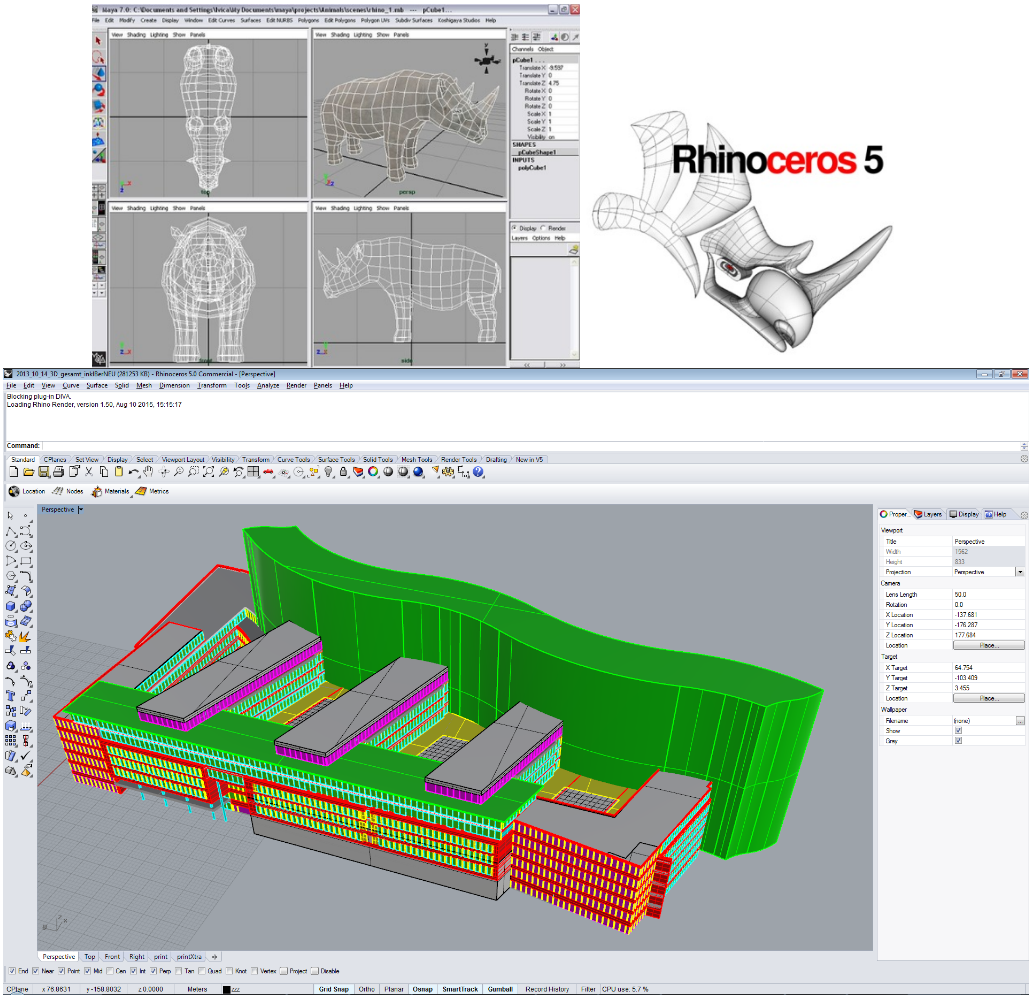


Figure 11: Screenshots of the Rhinoceros interface © www.rhino3d.com

Supplier, site, contact, last version, cost

Rhino 3D [http://www.rhino3d.com/] has been developed by Robert McNeel & Associates. The last released version is Rhinoceros 5. This version has the goal to reduce workflow bottlenecks that makes Rhino faster and able to handle larger models and project teams. Rhino 5 can be integrated with the following extensions: Penguin (for sketch and cartoon, non-photometric scan line renderer), Bongo (to create animations) and Flamingo (for a better light visualization).

The last version of the Rhino 5 costs 995€ for a single user. An upgrade is possible from any previous version for 495€ (single user). An advance package including all the extensions Rhino / Flamingo / Penguin / Bongo is available and costs 1695€ (single user).
The software is available for both Windows and Mac. Many plugins as Diva (a tool which performs environmental analysis for buildings) are available online [http://www.food4rhino.com/rhino-plugins/last-updated].

Functions

Rhino allows modelling every kind of shape, from simple 2D drawings to the most complex 3D free form surface. Because of the flexibility and accuracy of NURBS (non-uniform rational B-splines), Rhino models can be used in any process from illustration and animation to manufacturing. The fundamental geometric objects of the software are: points and curves, surfaces, polysurfaces and polygon mesh objects. Each NURBS surface can be translated into a polygonal mesh. With that it is able to import / export from / to a large number of other design tools. The Rhino advantage over using polygon modelers is that there are no facets so that, in rendering with Rhino, the models can be rendered at any resolution and a mesh can be created from the model without resolution limitation. With Rhino it is even possible to extract information from mesh objects and create NURBS models from that. Detailed information about surfaces can be extracted and visual surface analysis commands allow to analyse and validate surfaces (e.g. EMap command, curvature and edge analysis command).

Rhino capabilities in parametric design can be further improved with Grasshopper, a tool for computational design, which uses generative algorithms. Rhino is a command driven program and supports scripting via RhinoScript or Python and SDKs that provide tools to develop customized plugins for Rhinoceros in C++, C# or others.
Rhinoceros is provided with an easy and intuitive user interface, which makes it possible to have a contemporary visualization and control of top, fronts and perspective view of the drawing. Each view can be moved, rotated and zoomed independently of the others.

Design Stage, users

Rhino can be used in every stage of the project design, being suitable to create rapid 3D prototyping for a first product testing as well as to develop very precise 3D models addressed to the industrial production.

The software is used by architects, designers and engineers in architectural and construction design and is particularly suitable to industrial design. Makers of household and office appliances, furniture, medical and sports equipment, footwear, and jewellery use Rhino to create free-form shapes.

Results

Strength of Rhino is the capability to create complex free form surfaces. Included tools allow to extract detailed information of the geometry and to analyse and validate surfaces. Rhino has an easy to use interface, includes a command line and can import / export in a large number of file formats.

Import / Export

Rhino allows import / export in more than 30 files format. Importable and exportable files for the most used design tools are 3D Studio files (.3ds), Adobe illustrator files (.ai), SolidWorks models, Sketchup (.skp) and AutoCAD files (dwg, dxf). In addition, Rhino allows to import and export geometry as object files (.obj), GHS Geometry (gf, gft) and GNU triangulated surfaces (GTS). Also 2D and 3D points are importable and exportable in many formats (.pts, .asc, .txt, .csv, .xyz, .cgo).

Other importable / exportable file formats are: .sat, .dae, .cd, .x, .emf, .gf, .pm, .kmz, .gts, .iges, .igs, .lwo, .udo, .fbx, .x_t, .pdf, .pli, .pov, .raw, .rib, .step, .stp, .stl, .vda, .wrl, .vrml, .gdf, .wmf, .x3dv, .xaml,.xgl, .zpr.

References

http://www.rhino3d.com/

3.4. Sketchup

Source: M. Bodart / Université catholique de Louvain (UCL) Faculté d'architecture, d'ingénierie architecturale, d'urbanisme (LOCI), Belgium

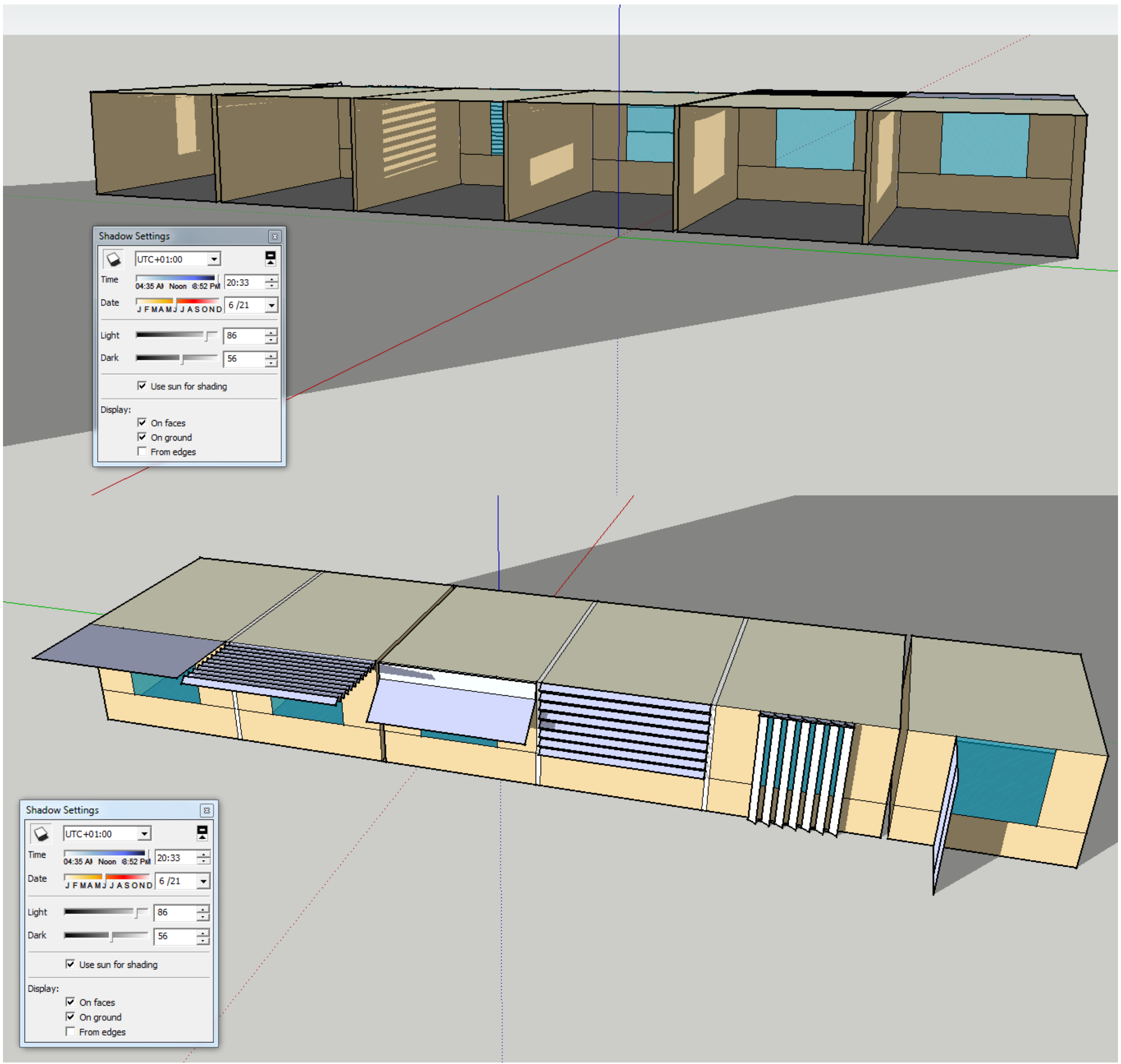


Figure 12: Screenshots of the Sketchup interface

Supplier, site, contact, last version, cost

SketchUp (formerly: Google Sketchup) is a 3D modeling program for applications such as architectural, interior design, civil and mechanical engineering, film, and video game design. A freeware version, SketchUp Make, and a paid version with additional functionality, SketchUp Pro, are available.

SketchUp is currently owned by Trimble Navigation, a mapping, surveying, and navigation equipment company. SketchUp was independent from 2000 to 2006 and then owned by Google from 2006 to 2012.

Sketchup is available on : http://www.sketchup.com/
One license of Sketchup Pro costs $590 USD.
Last version is SketchUp Pro 2015

Functions

SketchUp is a simple, very intuitive 3D modeling tool. The models that are built in SketchUp have precise dimensions, which can be drawn by using the mouse or simply by entering the dimensions by hand. Every SketchUp model is made up of just two components: edges and faces. Edges are straight lines, and faces are the 2D shapes that are created when several edges form a flat loop. In SketchUp, the extruding tool is very useful and allow to model 3D shapes by extruding 2D surfaces along predetermined paths.

SketchUp makes it easy to draw in 3D space by calling out helpful points in the modelling space, highlighting them with different colours and easy-to-understand tool tips. Examples are the midpoint of a line, tangency on an arc, perpendicularity of all kinds.

SketchUp Pro's Advanced Camera Tools allows the creation of customized views. It provides precise controls for settings the location of the camera, its focal length as well as the image width.

SketchUp proposes also advanced operations like area and volume calculations. SketchUp models can also be compatible with BIM tools as schema tags can be assigned to the groups or components of the model. It is also possible to create dynamic components. Dynamic Components are SketchUp objects that have been programmed to know what they are. These "smart" components can for example be scaled without being distorted. These components can also be programmed to move automatically; doors that swing open and solar panels that automatically face the sun are nifty examples.

SketchUp Pro uses the metadata embedded in the model to create tabular reports. The SketchUp's Match Photo tool allows the creation of a 3D model on basis of photographs. In SketchUp, it is also possible to create, optimize and alter 3D terrain.

SketchUp does not simulate daylight but its real-time "Shadow Engine" performs accurate shade studies on the model. Once the location of the model is fixed, the sun position can be determined and sun penetration as well as the effectiveness of shading devices can then be estimated.

Design Stage, users

The feature of Sketchup linked to daylighting is its ability to study the shadings, depending on the building location, the time zone and the date.

Import / Export

Sketchup Make allows the import of following formats:
.dwg, .dxf, .dae, .dem, .ddf, .kmz, .jpg, .pmg, .psd, .tif, .tga, .bmp

Sketchup Pro allows the import of following formats:
.3ds, .skp, .dwg, .dxf, .dae, .dem, .ddf, .kmz, .jdf, .xml, .osm, .jpg, .png, .psd, .tif, .tga, .bmp

The possible export formats of SketchUp Make are:
.3ds, .dwg, .dxf, .dae, .fbx, dae, .ifc, .kmz, .obj, .wrl, .xsi

The possible export of Sketchup Pro is:
.dae, .3ds, .dwg, .dxf, .fbx, .ifc, .kmz, .obj, .wrl, .xsi,

References

http://www.sketchup.com/

4. VISUALIZATION TOOLS

In their day-to-day practice, architects and designers often need to produce images of their projects, in order to fix their design, convince their clients or to win a competition.
These pictures show illuminated scenes (day-time or night-time scenarios) including light sources, colours, textures, shiny surfaces etc., trying to produce photorealistic effects. Sometimes, these images are produced on the basis of existing pictures (taken with a camera). Software like Photoshop are including specific functions (lighting effects) on that purpose. Some CAAD tools also embed specific extensions to produces these images from the 3D models.

The survey conducted within Subtask C1 showed that some people make confusion between Visualization and Simulation. Although they play an important role as a basis for discussion and can be crucial in order to explain the light in a room, they will in no way replace the result of light calculation programs (ray-tracing and other rendering techniques based on physics principles) and therefore, no special category will be set-up for these tools.

5. SIMULATION TOOLS

The following section on simulation tools is by no means comprehensive. The programs presented below were selected on the basis of their popularity amongst architects and because they hold particular promise for use in schematic design. For a comprehensive list of all simulation programs available, the US Department of Energy (DOE) Building Energy Software Tools Directory should be consulted at the following address: [apps1.eere.energy.gov/buildings/tools directory/].

5.1. Daysim

Source: M. Bodart / Université catholique de Louvain (UCL) Faculté d'architecture, d'ingénierie architecturale, d'urbanisme (LOCI), Belgium

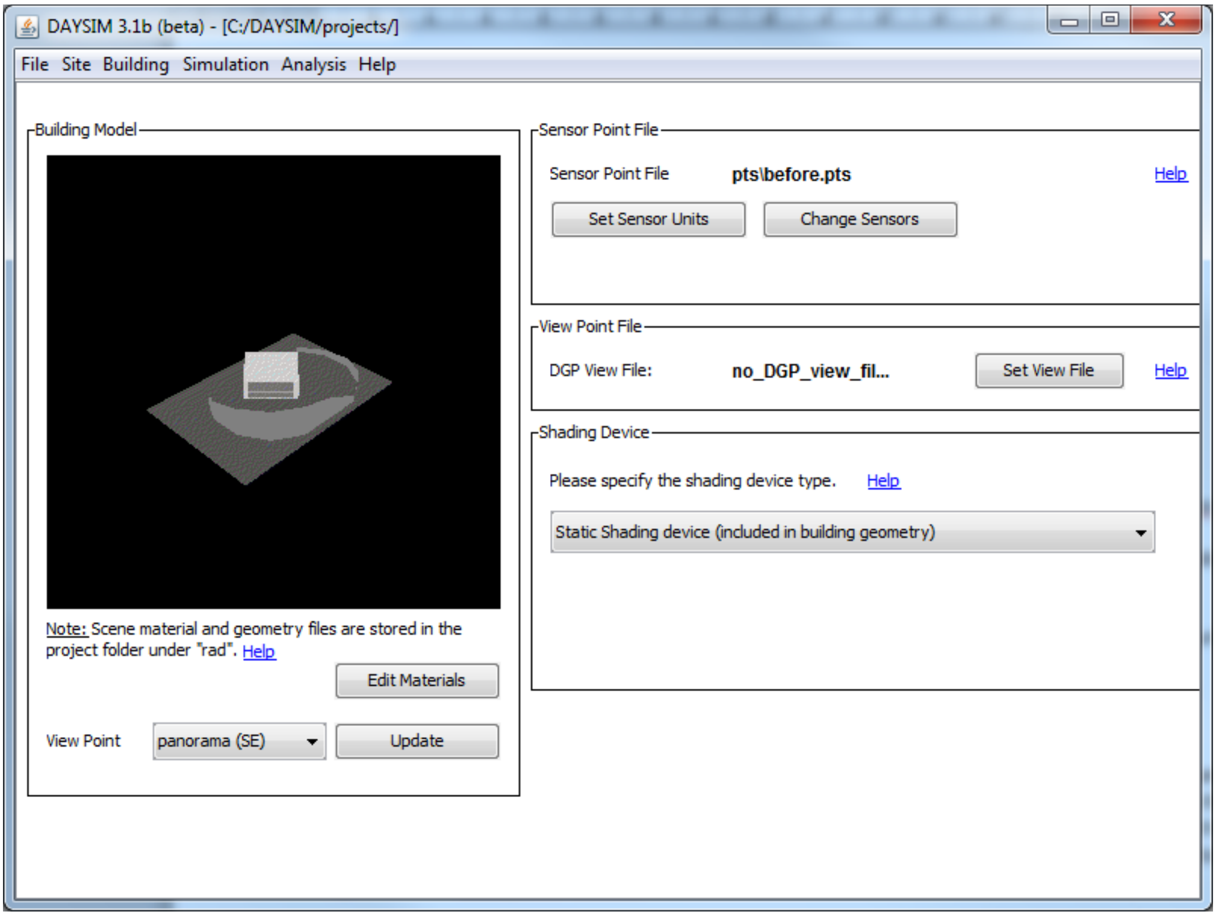


Figure 13: Screenshot of the Daysim interface

Supplier, site, contact, last version, cost

Daysim is free and available on the following website: http://daysim.ning.com/
The global illumination calculation in DAYSIM is based on the RADIANCE backward raytracer.
Last version is Daysim 4.0 but this version does not include any Graphical User Interface. DAYSIMps tool, developed by the Penn State University can however play this role. An older version of Daysim including a Graphical User Interface (version 3.1) is still available.

Functions

DAYSIM is a validated RADIANCE-based daylighting analysis software that models the annual amount of daylight in and around buildings. DAYSIM allows users to model static and dynamic facade systems. Users may specify electric lighting controls systems as manual light switches, occupancy sensors and photocell controlled dimming.

Design Stage, users

Daysim is used by designers, architects and engineers. As Daysim is based on RADIANCE, a minimum knowledge of RADIANCE is necessary in order to be able to make an informed choice of the simulation's parameters.

Description Procedure

The input files of Daysim are a geometry file and a material file that are written according to the Radiance format. Daysim file can thus be created in Sketchup and exported by the plugin su2ds or in ECOTECT.
The DIVA plugin including Daysim can also be included in the Rhinoceros 3D modelling tool.

Results

Simulation outputs range from climate-based daylighting metrics such as daylight autonomy and useful daylight illuminance to annual glare and annual electric lighting consumption, on basis on the installed electric lighting power. DAYSIM also generates hourly schedules for occupancy, electric lighting loads and shading device status, which can be directly coupled with thermal simulation engines such as EnergyPlus, eQuest and TRNSYS.

DAYSIM does not provide any rendering tool.

Import/export

As results, Daysim provide an html page as simulation report.
It gives a summary of the result, informing if the room would pass the LEED credits.
Separate results files containing the results of simulation can be imported in Excel.

References

http://daysim.ning.com/

5.2. DIALUX

Source: M. Bodart / Université catholique de Louvain (UCL) Faculté d'architecture, d'ingénierie architecturale, d'urbanisme (LOCI), Belgium

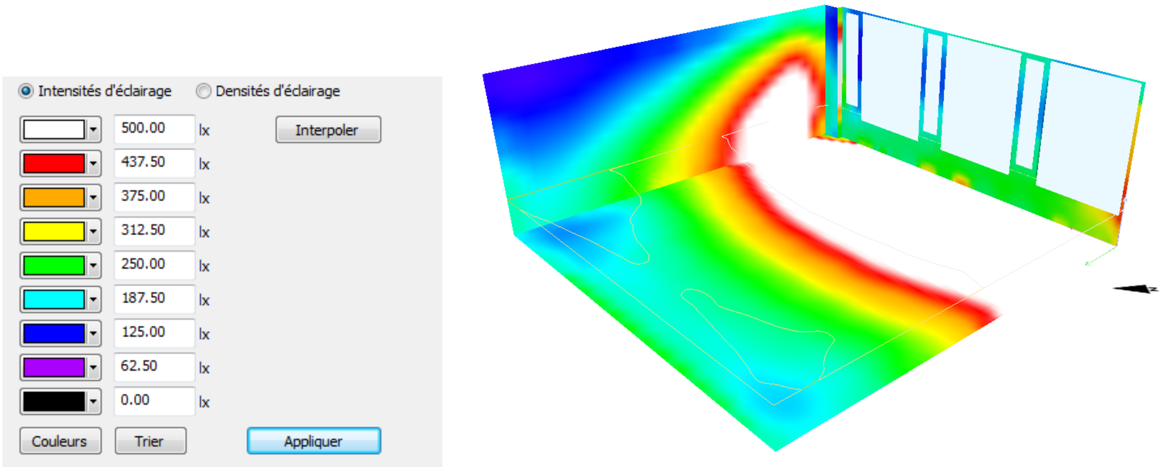


Figure 14: Screenshots of the results obtained with DIALUX

Supplier, site, contact, last version, cost

DIALUX is a free software tool developed by the German company DIAL in order to help lighting designers, architects and engineers to design their electric lighting system. It contains photometric data's from the major lighting manufacturers and is worldwide used. DIALUX allows to model one simple room, unlike DIALUX Evo which uses another calculation engine and allows considering the whole building.

Functions

DIALUX allows daylight calculations, for 3 types of sky, among which the CIE overcast sky.

Design Stage, users

DIALUX can be used at any stage of the project but as it does only include a simple modelling tool, it is, for daylight, better adapted to pre-design phases.
DIALUX is mainly intended for lighting designers but can be used by architects as well.

Description Procedure

The model is made in the software but one can import .dwg or .dxf file.

Results

For the rendering, DIALUX uses the radiosity method. In that case, the surfaces are considered as perfectly diffuse. If the internal materials are not perfectly diffuse, an adapted version of the raytracing software POV-Ray can be launched from the DIALUX graphical user interface. Raytracing can only be used for rendering, after a standard calculation in DIALUX, and the illuminance values are not affected by this step.

Import/export

Import and export of DWG and DXF files

References

http://www.dial.de

5.3. DIALux evo

Source: M. Bodart / Université catholique de Louvain (UCL) Faculté d'architecture, d'ingénierie architecturale, d'urbanisme (LOCI), Belgium

Supplier, site, contact, last version, cost

DIALux evo [www.dial.de] has been developed by DIAL GmbH, Germany. The last officially released version is Version 5. It is freely available on the web site : http://www.dial.de/DIAL/en/home.html and is available in several languages.

Functions

DIALUX Evo is the new software being introduced into practice in parallel to the software DIALUX and that will replace DIALux in the future. The decisive conceptual innovation in DIALUX Evo is the building concept.

The user creates geometry in a virtual space. This can be a single room which is to be planned as a model or a whole floor or even a whole building or several buildings in an urban context. If a planner designs the lighting for a whole building then he can position himself anywhere and view the result of his plan.

DIALUX allows electric and daylight calculation. Clear, average and overcast skies can be modelled. Illuminance values as well as daylight factor can be calculated.

Design Stage, users

DIALUX Evo is less intuitive than DIALUX and is probably more devoted to lighting designers than to architects.

Description Procedure

Building can be modelled in DIALUX Evo, from dwg files or not.

Results

As it is the radiosity method which is used in DIALux, in DIALUX Evo, it is ray-tracing which is employed. This method allows calculating much larger and more complex scenes than previously and, for similar scenes, the calculation time is shorter.

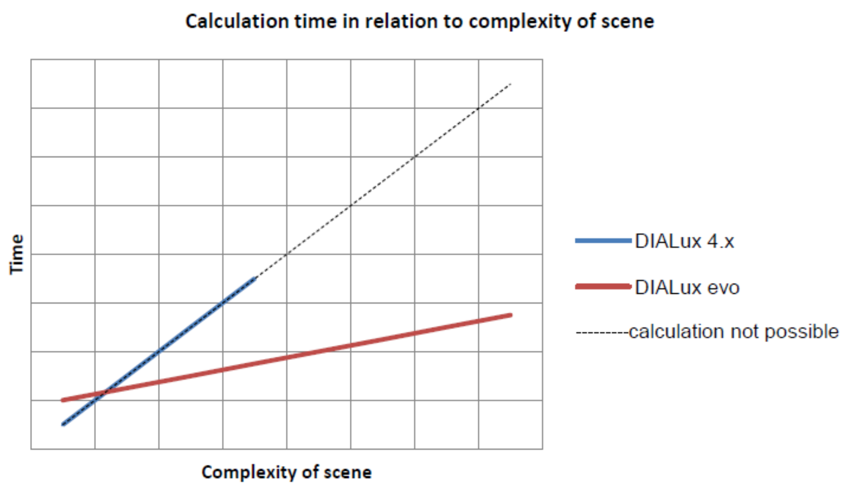


Figure 15: Calculation time in relation to complexity of scene in DIALux 4.x and DIALUX evo

Import/export

DWG files can be imported. The building can thus be easily constructed from the plan. The manufacturers of luminaires and façade components have to pay an annual fee to be represented in the DIALux evo database.

References

DIALux evo – New calculation method
http://www.dial.de/DIAL/en/company/press-announcement/dialux/dialux-evo-1.html
http://www.dial.de/DIAL/fr/lentreprise/point-presse/dialux/dialux-evo-1.html

5.4. DIAL+lighting

Source: B. Paule / Estia SA, Switzerland

Figure 16: Illustration of the 4 simulation modules of DIAL+, ©Estia

Supplier, site, contact, last version, cost

The DIAL+ suite (www.dialplus.ch) has been jointly developed by Estia SA and the Swiss Federal Institute for Technology, Lausanne (LAURE-EPFL). DIAL+ is distributed by Estia SA, Lausanne. (dial@estia.ch)

The last released version is version 2.3. This software suite is composed of two simulation modules dealing respectively with:

- Daylighting & Electric Lighting: DIAL+Lighting
- Dynamic thermal simulation & Natural ventilation: DIAL+Cooling

Free demo version available on www.dialplus.ch. Free for non-commercial/Academic use. For professional use, please see the dialplus website for latest prices.

DIAL+ is available for Windows and Mac OS X

There are five language options: English, French, German, Italian and Spanish. The user guide is available in English and French.

Functions

DIAL+ allows to either launch lighting simulations (Radiance®) or to calculate the thermal and cooling loads on the room scale.

The lighting module allows producing reports that include the following results:

- Daylight factor values,
- Diffuse Daylighting Autonomy values (% and hours),
- Autonomy for Minergie-ECO® (Swiss),
- Illuminance values due to electric lighting,
- Annual lighting electricity consumption (SIA 380/4, Minergie®),
- Sunpath diagram including outdoor obstructions,
- Shading studies (sunshine factor, viewed sky fraction).
- The cooling module gives access to the following results:
- Heating & Cooling loads (EN 15251 EN 15255, EN 15265 and ISO 13791, SIA 382/1 SIA 382/2)
- Air flows due to natural ventilation (Cockroft model).

The lighting module of DIAL+ has been validated against the following standards:

- CIE 171:2006 “Test Cases to Assess the Accuracy of Lighting Computer Programs”.
- The cooling module of DIAL+ has been validated against the following standards:
- ISO-13792: 2004, “Thermal performance of buildings - Calculation of internal temperatures of a room in summer without mechanical cooling - General criteria and validation procedures”.
- EN-15255: 2007, “Energy performance of buildings - Sensible room cooling load calculation - General criteria and validation procedures”.
- EN-15265: 2008, “Energy performance of buildings - Calculation of energy needs for space heating and cooling using dynamic methods - General criteria and validation procedures”

Design Stage, users

DIAL+ is very adapted to the optimization stage of the design process. Its speed and simplicity allow realizing very quickly parametric studies and comparing the different variants of a given facade.

The interface was designed so that a non-expert user can easily describe all the room parameters and it can thus be used either by engineers and architects. It is also very well suited for educational purposes. However, the use of all the features (lighting and thermal) assumes that the user has a minimum educational background regarding building behaviour.

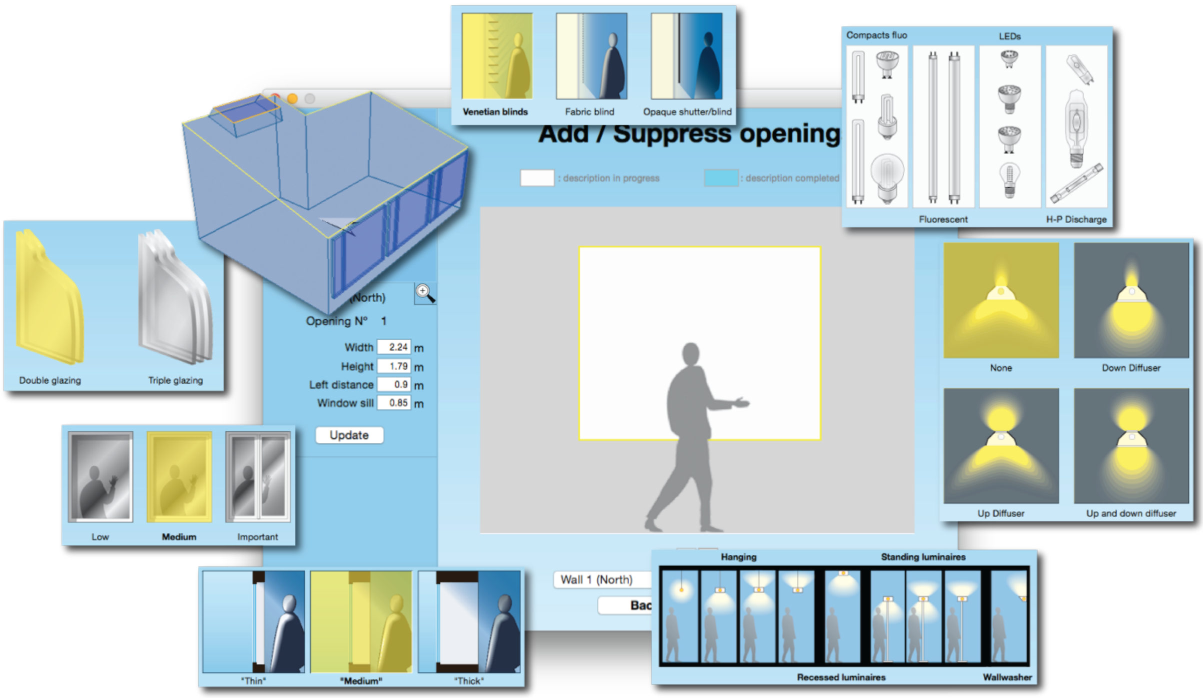


Figure 17: Illustration of the input parameters aiming to facilitate the room description

Description Procedure

DIAL+ includes a simplified 3D modeller dealing with the description of rectangular, L-shape or trapeze rooms fitted with horizontal, mono-pitch or ridge roofs. The complexity of the internal geometry may be supplemented by the addition of opaque or transparent objects. The average time requested to describe all the parameters of a typical room requires less than 10 minutes.

Results

The simulations results are displayed with 2D maps and graphs (DF, Autonomy, Illuminance, etc.) on the workplane or on the walls.

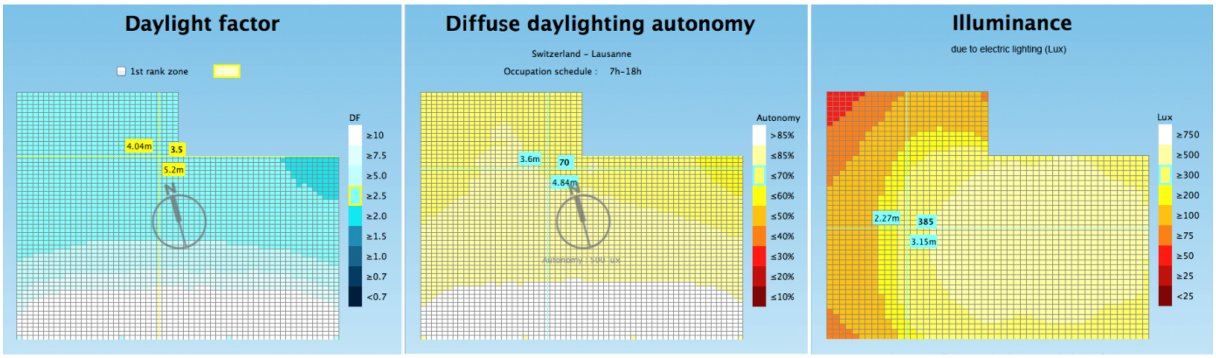


Figure 18: Screenshots of three typical lighting simulation results from DIAL+

Import/export

There are no possibilities to import models from existing CAD systems. As far as DIAL+ focuses on rooms, the time to describe the problem with the embedded interface is shorter than the time requested to clean up external files and to complete them with all the requested parameters.

For electric lighting, it is possible to import existing luminaires files (.ldt).
Weather data as well as utilization & occupation profiles or specific walls composition can be imported as text files.

After simulation, DIAL+ displays the result output optionally as graph, grid or tables, which later can be exported to clip board or file as .csv or .jpeg. The final reports containing all information about the room model and users function can be printed or edited as .pdf files.

References

- Estia: “DIAL+Lighting Validation case test CIE-171-2006”, February 2013, Lausanne, Switzerland.
- B. Paule, F. Flourentzou, S. Pantet, J. Boutillier: “DIAL+Suite, a complete but simple suite of tools to optimize the global performance of building openings. Daylight / Natural Ventilation / Overheating Risks”. Proceedings of the CISBAT’11 Conference, Lausanne, 2011.
- http://www.diaplus.ch
- http://www.buildingenergysoftwaretools.com/
- http://www.minergie.ch/documents-minergie-eco.html

5.5. DIVA-for-Rhino

Source: M-C Dubois, Energy and Building Design, Lund University, Sweden

Supplier, site, contact, last version, cost

DIVA for Rhino is available for download and purchase from the Solemma LLC website (http://www.solemma.net/DIVA-for-Rhino/DIVA-for-Rhino.html). A basic requirement to be able to run DIVA-for-Rhino is to have installed a version of the NURB modeler Rhinoceros, i.e. at least Rhino 4.0 SR9. It is possible to obtain a free trial license for a period of 30 days as well as a free educational license for students and educators. A commercial single-user license costs $470 USD. It is also possible to install a site license for multiple users.

Functions

According to (Solemma LLC, 2015),
DIVA-for-Rhino is a highly optimized daylighting and energy modeling plug-in for the Rhinoceros - NURBS modeler. The plug-in was initially developed at the Graduate School of Design at Harvard University and is now distributed and developed by Solemma LLC. DIVA-for-Rhino allows users to carry out a series of environmental performance evaluations of individual buildings and urban landscapes including Radiation Maps, Photorealistic Renderings (see e.g. Figure 19), Climate-Based Daylighting Metrics, Annual and Individual Time Step Glare Analysis, LEED and CHPS Daylighting Compliance, and Single Thermal Zone Energy and Load Calculations (see Figure 20).

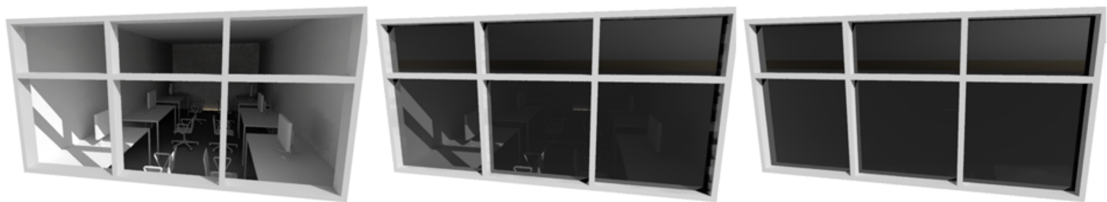


Figure 19: Visualization of a switchable three-state electrochromic window,
source: http://www.solemma.net/development.html

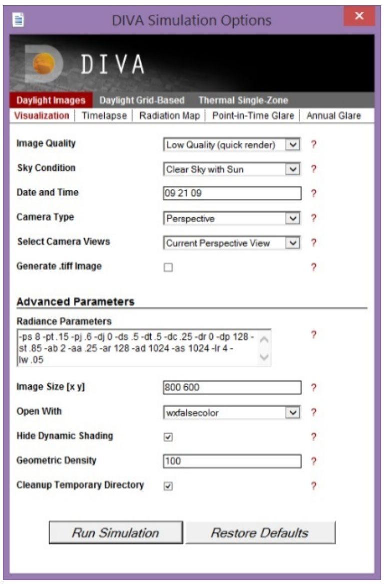


Figure 20: Diva simulation options menu showing the possibility to produce visualizations, timelapse, radiation maps, point-in-time glare, and annual glare calculations

Design Stage, users

This tool is dedicated to professionals of the building construction sector, such as architects and lighting designers familiar with computer design tools. The input is performed mainly through the Rhinoceros interface so knowledge of Rhinoceros is absolutely essential. The daylight or light analysis then requires that a climate file is downloaded and that a grid of nodes for analysis is selected. The calculation of different metrics or renderings can then be performed easily through the DIVA interface.
Some advanced knowledge of daylighting/lighting simulation is required however as one must also set surfaces pointing in the right direction, give appropriate material properties (reflectance, transmittance, etc), model a relevant surrounding (buildings and obstacles) that will affect the output, and select specific Radiance rendering settings for the calculation.

Description procedure

DIVA-for-Rhino can generate climate-specific annual surface irradiation images (see e.g. Figure 21) or calculate annual irradiation at node locations. The program can be used on an urban or building scale to identify locations with solar energy conversion potential or areas in need of shading due to excessive solar exposure. The analysis uses a method described by (Robinson & Stone, 2004) which harnesses a Radiance module called GenCumulativeSky to create a continuous cumulative sky radiance distribution.

The program also performs point-in-time glare simulation, where the visual comfort of a person under the simulated conditions at the camera viewpoint can be simulated. The Daylight Glare Probability (DGP) metric is used in the comfort evaluation which considers the overall brightness of the view, position of 'glare' sources and visual contrast, see Figure 22. An annual glare calculation uses a similar methodology as a Point-in-Time Glare image; however, the process is repeated for each hour in the year by using an annual DAYSIM prediction to calculate vertical eye illuminance and images with the ambient calculation turned off to predict contrast from direct sunlight. This produces an annual evaluation of comfort within a space.

Results

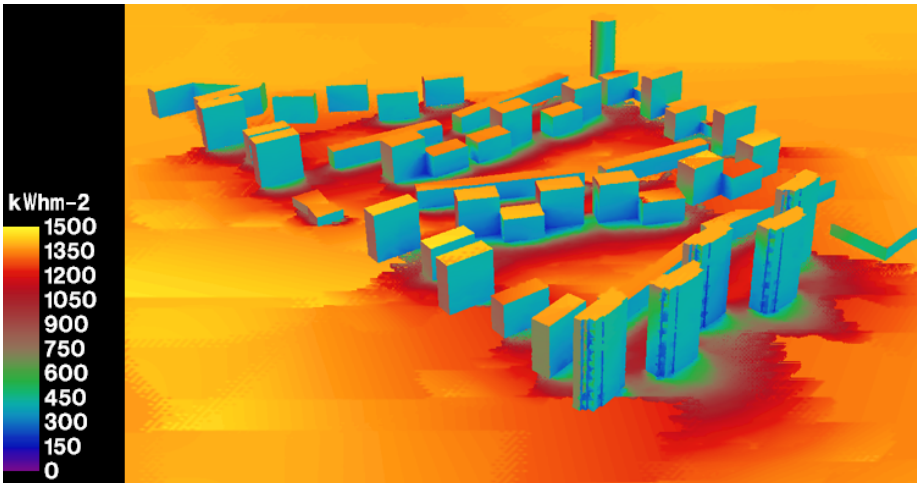


Figure 21: Example of a radiation map generated in DIVA using rpict and gencumulativesky.
Source: http://www.solemma.net/index.html

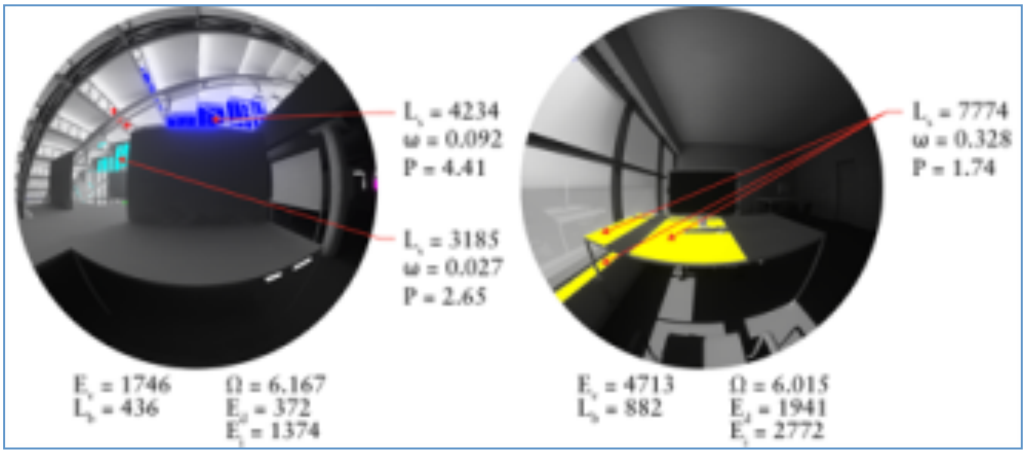


Figure 22: Examples of visual comfort analysis in DIVA. Areas of high contrast (3 times the mean image luminance) are highlighted in color.
Source: http://diva4rhino.com/user-guide/simulation-types/point-in-time-glare

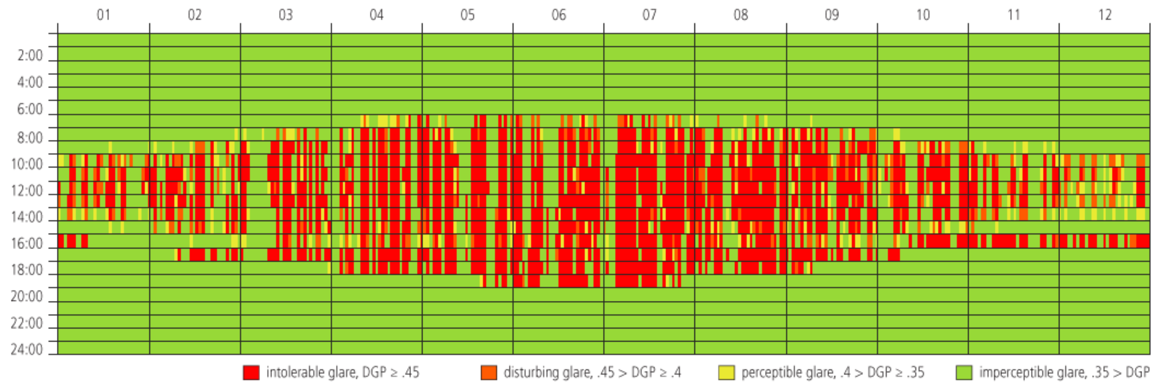


Figure 23: Output from an annual glare calculation with no dynamic shading devices.
Source: http://diva4rhino.com/user-guide/simulation-types/annual-glare

Other results are shown in § 7.2.6 (daylight factor values, Illuminance due to electric lighting, 3D visualization).

Import/export

The simulation output of the daylight factor is saved in a text file format or produced as a false-color image superposed on the building surface to analyse (in the Rhinoceros building modelling interface). The output file may be exported to Excel for further analysis. The rendered images can be saved in any graphical format (jpg, bmp, etc).

References

Robinson, D., & Stone, A. (2004). Irradiation modelling made simple: the cumulative sky approach and its applications. Plea2004 - The 21st Conference on Passive and Low Energy Architecture. Eindhoven, The Netherlands, 19 - 22.

Solemma LLC. (2014). Retrieved 08 04, 2014, from Diva for Rhino:

http://diva4rhino.com/?xg_source=msg_mes_network

http://www.solemma.net/DIVA-for-Rhino/DIVA-for-Rhino.html

5.6. FENER

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

Supplier, site, contact, last version, cost

Fraunhofer ISE has developed a web-based simulation platform that uses state-of-the-art numerical techniques to evaluate the daylighting, glare and energy performance of fenestration systems and their control. The web interface creates a link to run Fener simulations at Fraunhofer ISE's supercomputers. https://fener-webport.ise.fraunhofer.de/

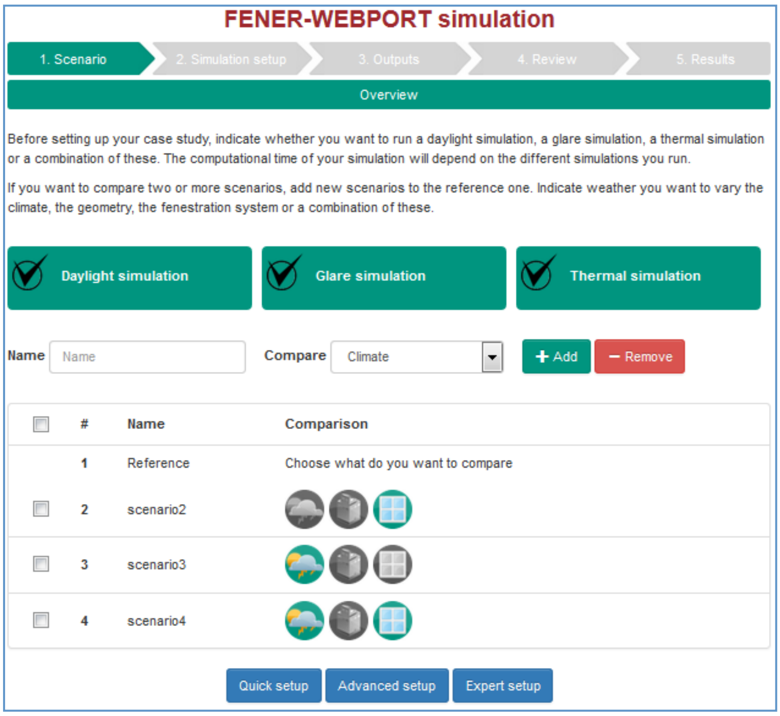


Figure 24: Fener-Webport main page

Functions

Fener is used to compare scenarios in terms of climate, geometry or fenestration systems, calculating dynamic energy, daylight and glare metrics. The main functions of the tool are the following :

- **User-friendly interface:** the tool guides the user introducing all the inputs required to set up Fener simulations. Three different setup modes are available:
  - Quick: predefined set of geometries and boundary conditions.
  - Expert: allows flexibility in the definition of geometry and boundary conditions by manipulating configuration files.
- **Database**: the tool includes a database from which the characterization data (BSDF and calorimetric data) of fenestration systems can be selected. New system data can be uploaded.
- **Control strategies**: the tool allows for user-defined control strategies. The user can specify a matrix of control states depending on occupation, illuminance, glare index, temperature and solar radiation setpoints.

Other features :

- It can be opened in different portable devices.

- It includes an interactive 3D visualization of the geometry.

Design Stage, users

The aim of this tool is twofold:

- To facilitate the development of new façade products by manufactures of façade components.
- To quantify the benefits of selecting one or another fenestration system by architects and building planners in the initial stages of their projects.

Description Procedure

The geometric representation of the space consists of a rotatable rectangular shoe-box zone.
The tool includes an interactive 3D visualization of the geometry.

Results

Plotting capabilities include temporal maps of glare, bar graphs of cooling, heating and lighting energy demand, and temporal evolution of different metrics.

Fill the control state matrix under the following conditions:

Average illuminance	Indoor temperature	Daylight glare index (DGP)	Control state
< illuminance setpoint	> indoor temperature setpoint	> 0.45	Control state
No	No	No	Fully coloured electroc
Yes	No	No	Fully coloured electroc
No	Yes	No	Fully coloured electroc

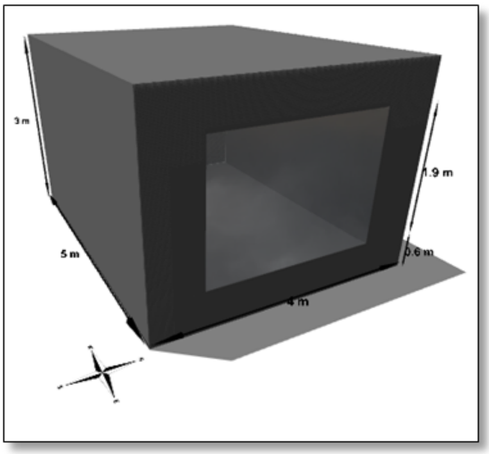


Figure 25: (left) Definition of control strategies in Fener, (right) visualization of the geometry

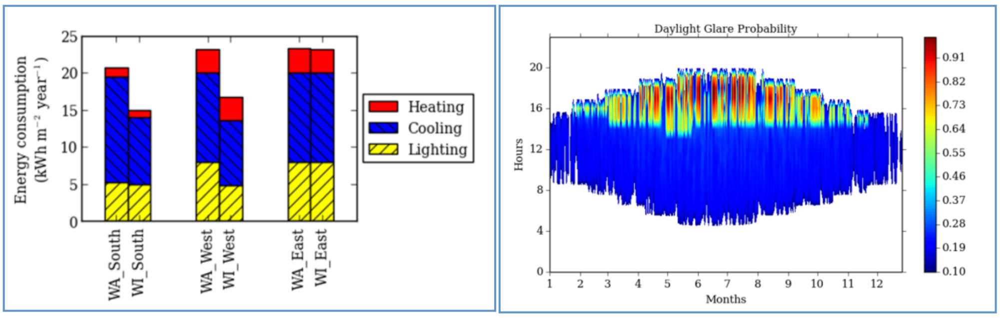


Figure 26: Fener output examples: (left) bars of heating, cooling and lighting energy consumption, (right) temporal map of daylight glare probability - No rendering of indoor illuminance conditions is included in this tool.

No rendering of indoor illuminance conditions is included in this tool.

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

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

5.7. GERONIMO

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

Supplier, site, contact, last version, cost

GERONIMO [http://leso.epfl.ch/geronimo] has been developed by the Solar Energy and Building Physics Laboratory (LESO-PB) at EPFL (Switzerland). The last officially released version is Version 1.1. Geronimo is free of charge and available from the homepage of LESO-PB / EPFL.

Functions

GERONIMO is a user-friendly software for architects and lighting designers conceived to perform daylighting calculations for clear and overcast skies. It allows visualizing the impact of Complex Fenestration Systems (CFS) in office buildings for those different sky types. The advanced features of GERONIMO are described in §5.1.4 of the C5 Section. The rendering engine of GERONIMO is the backward ray-tracing software RADIANCE. GERONIMO avoids the classical command-line usage of Radiance offering the use of a simple interface, which can be adapted to the user's skills.

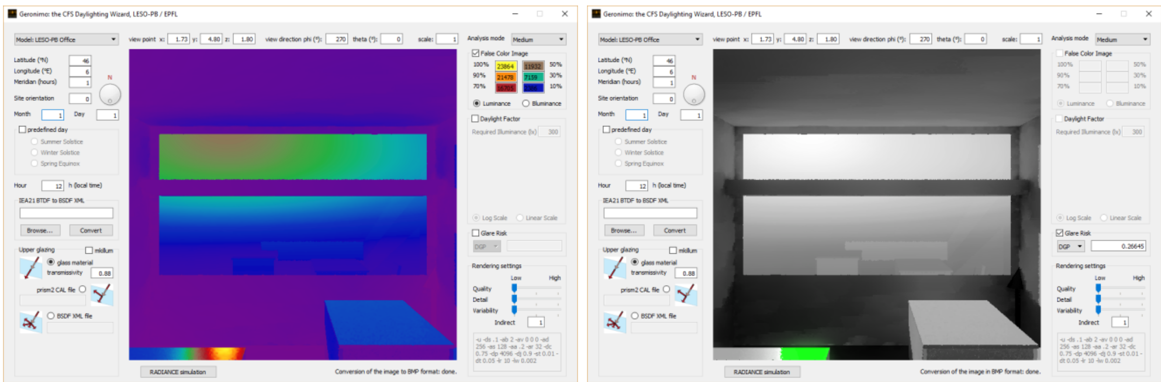


Figure 27: The falsecolor illuminance calculation (left) and the glare calculation (right) in the daylight analysis tools

Design Stage, users

Professionals of the building construction sector, such as architects and lighting designers familiar with computer design tools. Three Analysis modes are present within GERONIMO: Basic, Medium and Advanced. The Basic mode allows any user to produce a rendering, and the Advanced mode allows the specialized user to control the RADIANCE parameters.

Description Procedure

GERONIMO does not include 3D modelling functionality; instead it provides 6 office typologies that are representatives of common configurations. The way to deal with custom 3D Models in GERONIMO is left to advanced users as a RADIANCE model must be created and plugged in a dedicated simulation file in GERONIMO. GERONIMO only deals with daylight and has no electric lighting capability.

Results

GERONIMO allows to render false colour images of illuminance and circadian weighted illuminance. It allows to compute the Daylight Factor and displays the values in grey-scale using a linear or logarithmic scale. It can compute the Glare Risks by calling evalglare and can display the different glare indices. It contains a Diffuse Daylight Autonomy calculation realized with a single rendering under an overcast sky.

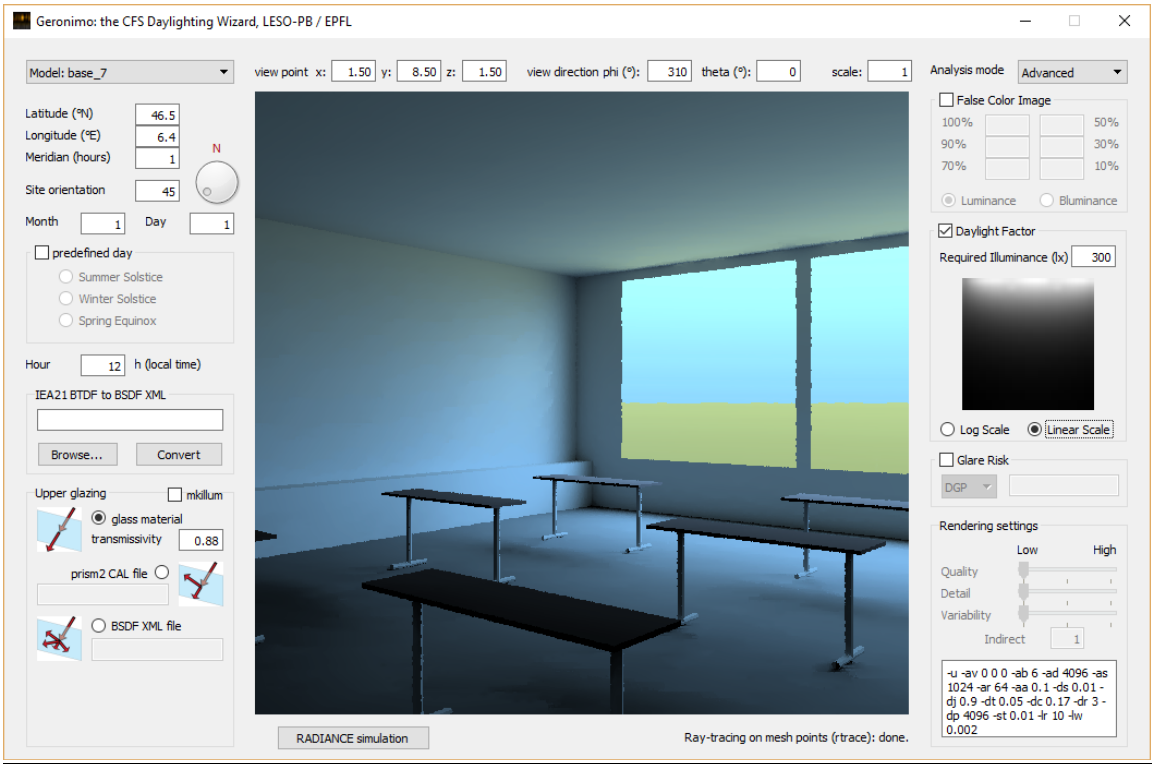


Figure 28: The daylight factor calculation with an overcast sky

Import/export

The simulation output of the daylight factor is saved in a text file format that can be opened in any spread sheet and in a BMP image in grey-scale. The rendered images are saved in BMP format.

References

J.H. Kämpf, J.-L. Scartezzini, Ray-Tracing Simulation of Complex Fenestration Systems Based on Digitally Processed BTDF Data, Proc. of International Conference CISBAT 2011, Lausanne 14-16 September 2011

J. Kämpf, J.-L. Scartezzini, GERONIMO: the CFS Daylighting Wizard, Paper presented at 4th Velux Daylight Symposium, Lausanne, 2011

5.8. IES VE

Source: Michael Jørgensen from COWI, Denmark

Supplier, site, contact, last version, cost

The program is developed by Integrated Environmental Solutions Limited. The latest version is 2014.1.1.0. The program is updated regularly and can be downloaded from iesve.com. The program is not freeware and the cost of the program depends on how many applications you wish and which license option you chose. The following description is put together from various guides and descriptions from IES homepage.

Functions

The <Virtual Environment> is an integrated suite of applications linked by a Common User Interface and a single Integrated Data Model (IDM). This means that all the applications have a consistent "look and feel" and that data input for one application can be used by the others. Modules such as "ApacheSim" for thermal simulation, "Radiance" for lighting simulation, and "SunCast" for solar shading analysis exist. "ModelIT" is the application used for input of 3D geometry used to describe the model.

Design Stage, users

There is no limitation regarding the geometric complexity but the counterpart is that the input process is complex. The calculation time is quite long. IES-VE is mainly dedicated to specialists and is well suited to conduct global building analysis (including thermal dynamic simulations).

Description Procedure

ModelIT allows the user to create the 3D models required by other components within the <Virtual Environment>. ModelIT is designed to enable appropriate levels of complexity to be incorporated within a model across the entire design spectrum. At the sketch design or feasibility stage, basic models may be generated from scratch using a variety of simple modelling tools, in order to conduct preliminary performance appraisals or comparative studies. Similarly, at the other end of the design process, fully worked DXF files may be attached to ModelIT and using the tools provided, three-dimensional building spaces may be generated rapidly by tracing over the DXF outlines.

Results

The Radiance interface module RadianceIES is integrated into the Virtual Environment Framework. RadianceIES interface can be treated as a stand-alone module. The 3D geometry of the model created by ModelIT is converted by an internal module (mit2rad) which is hidden to the user. Global properties are inherited from the ModelIT database e.g. site data, and default properties are assumed for other data requirements e.g. surface colours, etc.

There are two types of picture file created by Radiance, luminance and illuminance. An illuminance picture can be used to look at Lux values and generate Lux or DF contours, a luminance picture can be used to generate glare indices or as a photo-realistic image. The interface program RadianceIES allows the user to create the two data files, the view file (*.rdv) and the parameter file (*.rdp), that control the image generation program, rpict. The raw image file is filtered and scaled by the program pfilt to create the picture file (*.pic). The interface is designed to make things as easy as possible for the user to create images by making default assumptions where possible.

Import/export

The VE is linked to Autodesk Revit through plugins that allow users to build models in Revit and then analyse them using a range of products with the <Virtual Environment> family. Integration with other BIM tools is achieved by importing data in a gbXML format into the <Virtual Environment>. The analysis tools include annual energy/carbon consumption, building loads, daylighting and electric lighting, climate, water, air flow and LEED/BREEAM/Greenstar credits.
VE is also linked with Trimble Sketchup through a plugin that allow users to building and import models in IES.

References

http://www.iesve.com/Software/

5.9. Lightsolve

Source: J. Wienold / LIPID /Ecole Polytechnique Fédérale de Lausanne, Switzerland

Supplier, site, contact, last version, cost

Lightsolve is an early design stage daylighting software being developed by LIPID EPFL for academic and research purposes. The application bundle is provided for free to students, researchers and practitioners interested in testing the tool and can be downloaded here: http://lightsolve.epfl.ch
The software is available on both Mac OSX and Windows systems. The current version is 0.4.5.

Functions

The general approach for Lightsolve is to inform well-balanced daylight design during early design stages through an interactive visualization and a pro-active, guided improvement of full- year time-varied daylighting performance. The metrics used in Lightsolve differ from most existing daylighting simulation programs in two ways: they are goal-based and they place emphasis on the variation of daylight performance over the day and the year by use of temporal maps.

Figure 29: Screenshot of the results obtained with Lightsolve

At the moment five different aspects can be evaluated within Lightsolve:
1. Time based illuminance analysis
2. Time and view point dependent glare analysis (based on DGP)
3. Perceptual contrast analysis
4. Variability (contrast over time) analysis
5. Non-visual effect evaluation (health)

A daylight factor analysis is implemented as well.

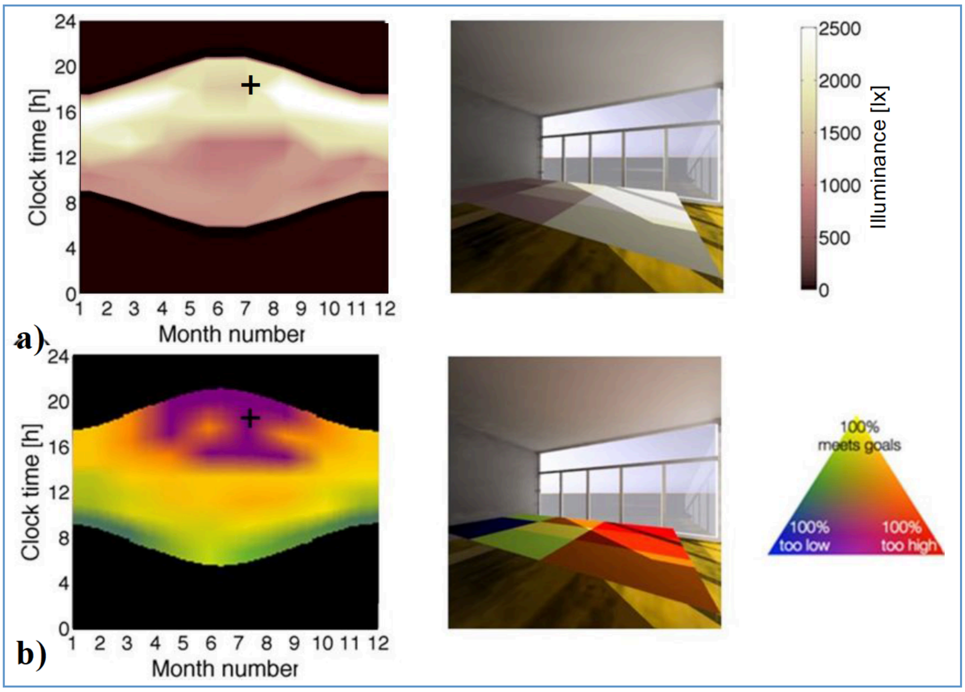


Figure 30: Time-based illuminance analysis (left) with associated rendering at given moment (right and cursor) on an absolute (a) and goal-based scale (b)

The core of Lightsolve is based on two raytracing engines:

1. A tailored-on-measure engine, relying on NVidia OptiX as a real-time ray-tracing tool to ensure high responsiveness and interactivity with the scene. It also allows the definition of the surfaces of interest (sensors) and to display the results in the 3D scene, a key feature not to lose the spatial reference when looking at the results
2. Radiance as daylighting simulation engine

The OptiX based engine can be used in tandem or instead of Radiance, even it might be less accurate than Radiance itself. Despite that, its high speed in producing realistic results made it possible for the user to assess the performance of his own designs over a single exercise session rather than a dedicated project.

Design Stage, users

Lightsolve is a **beta software** being developed by LIPID EPFL for academic and research purposes. The application bundle is provided for free, "as is" and without warranties to students, researchers and practitioners interested in testing the tool. It is intended primarily for academic use and to collect feedback as it has not yet been fully validated.

Description Procedure

Lightsolve does not provide 3D modelling functionality, but allows importing Wavefront OBJ as well as Sketchup SKP files.

Results

The rendering method was tailored on measure balancing quality, reactivity and rendering speed. It is based on stochastic backward ray tracing. Global direct illumination is pre-computed and stored as a 3D light map (as in photon mapping). When the point of view is changed, the engine progressively traces the indirect illumination using the pre-computed map and displays the final image. Thanks to the fast rendering, it is possible for the users to freely navigate in the 3D model and have a first visual feedback on the lighting conditions at different times of the day/year.

Import/export

Wavefront OBJ as well as Sketchup SKP file formats are supported by Lightsolve. The results of the rendering can be exported as High Dynamic Range images (*.hdr) or Portable Network Graphics (*.png) for external usage. The point grid calculation result of illuminances is exported in .csv format for evaluations.

References

Interactive expert support for early stage full-year daylighting design: a user's perspective on Lightsolve. M. Andersen, J. M. L. Gagne and S. Kleindienst. Automation in Construction, vol. 35, p. 338-352, 2013.

An Interactive Expert System for Daylighting Design Exploration. J. M. L. Gagne, M. Andersen and L. K. Norford. Building and Environment (ISSN: 0360-1323), vol. 46, num. 11, p. 2351-2364, 2011.

http://lightsolve.epfl.ch

5.10. Radiance

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

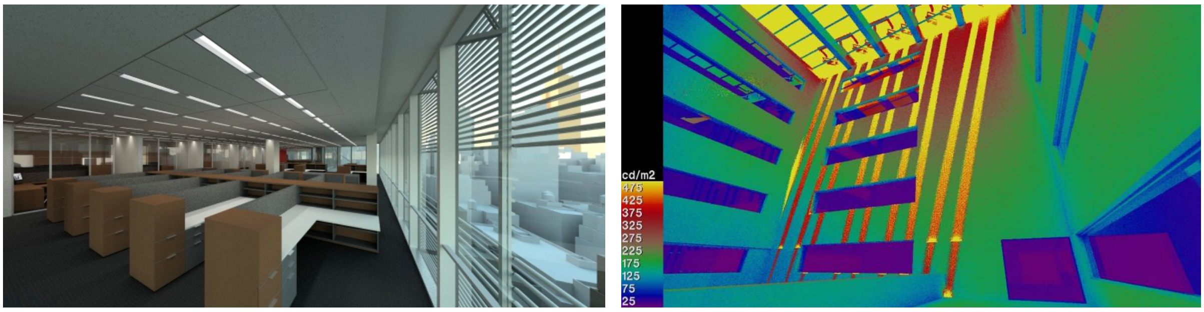


Figure 31: Screenshots of the results obtained with Radiance (Left: © www.radiance-online.org, Right: © Bartenbach GmbH)

Supplier, site, contact, last version, cost

Radiance [http://www.radiance-online.org/] has been developed by Greg Ward at Lawrence Berkeley National Laboratory (LBNL). The last version officially released by LBNL is Radiance 5.0, which has been published in September 2015. It is available as source code for installation under any OS (Windows, Linux, Mac). Additionally, the source of the latest, unofficial HEAD release can be downloaded, but this may contain untested modules or undetected bugs. The National Renewable Energy Laboratory (NREL) provides up-to-date compiled packages of recent HEAD versions for Windows, Mac and Linux. [https://openstudio.nrel.gov/getting-started-developer/getting-started-radiance].

The Radiance package includes programs for modelling and translating scene geometry, luminaire data and material properties, all of which are needed as input to the simulation. The software is free and is published under an open source license.

Functions

Radiance is a sophisticated tool for analysis and visualization of lighting. It takes 3D geometric models as input and allows calculating physically correct results and high quality renderings (luminance / illuminance values and images). Falsecolor and isoline presentations simplify the understanding of the results. There are hardly any limitations on geometry and materials, which can be defined based on built-in models or via data input based on measurements of color and bidirectional scattering distribution functions (BSDF).

Radiance is kind of state-of-the-art for daylight simulations. Simulations can be performed using different CIE skies (clear, uniform, overcast) or the Perez all weather sky model. With an additional plugin even the 15 new CIE skies are available. The Perez model is also the basis for annual daylight simulations based on measured climate data. 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.

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.

Radiance has been validated against the CIE 171:2006 “Test Cases to Assess the Accuracy of Lighting Computer Programs”:

- D. Geisler-Moroder, A. Dür, Validation of Radiance against CIE171:2006 and Improved Adaptive Subdivision of Circular Light Sources, 7th International Radiance Workshop, Fribourg, 2007, online: http://www.radiance-

online.org/community/workshops/2008-fribourg/Content/Geisler-Moroder/RW2008_DGM_AD.pdf
- D. Geisler-Moroder, Accuracy Improvements for Computational Methods and Color Rendering Index Calculations in Global Illumination Model, Dissertation, University of Innsbruck, 2010.

Design Stage, users

Radiance is used by designers, architects and engineers to predict light levels and appearance of a space with various artificial lighting and daylighting concepts prior to construction. Researchers also use it to evaluate new lighting products.
The software can be used in each stage of lighting design for daylighting and artificial lighting simulations. It allows the simulation of a wide variety of space geometries and lighting conditions.

Description Procedure

As a command line tool, Radiance does not include a 3D modelling engine. The geometry and material definitions have to be textual input. While defining the geometry directly in Radiance is not easy to handle, there are many methods to import CAD geometry via converted files. 3D geometry can for example be imported with the obj2rad tool from .obj files, exported from Sketchup with the su2rad plug in or directly exported from Ecotect in .rad and .mat file formats.

Results

The rendering method is based on hybrid deterministic and stochastic (Monte Carlo) backward ray tracing. Direct illumination levels and specular reflections are calculated deterministically, while indirect diffuse contributions are evaluated through MC sampling. The results of the rendering are exported as high dynamic range images (*.hdr).

Import / Export

Radiance provides various file format converters for input and output. To import models into Radiance, obj2rad converts Wavefront .obj files, mgf2rad does the same for the Materials and Geometry Format .mgf. Luminaire data in .ies format can be imported using the tool ies2rad.
Radiance exports RGBE HDR images in the original HDR file format that can be converted to various image formats such as .bmp, .gif, .pict, .ppm, .ps or .tiff for external usage. The point grid calculation results of luminances and illuminances are exported in text format that can be further used in a spreadsheet for evaluations.

References

Geisler-Moroder, David, and Arne Dür. 2008. “Validation of Radiance against CIE171:2006 and Improved Adaptive Subdivision of Circular Light Sources.” In 7th International RADIANCE Workshop. Fribourg, Switzerland.

Radiance Online. 2015. www.radiance-online.org

Ward, Greg, and Rob A. Shakespeare. 1998. “Rendering with RADIANCE.” The Art and Science of Lighting Visualization.

Ward, G, R Mistrick, E S Lee, A Mcneil, and J Jonsson. 2011. “Simulating the Daylight Performance of Complex Fenestration Systems Using Bidirectional Scattering Distribution Functions within Radiance”.

http://www.radiance-online.org/

5.11. ReluxPro

Source : J. Kaempf, LESO-PB, Ecole Polytechnique Fédérale de Lausanne, Switzerland and M. Hegi, Relux Informatik AG, Switzerland

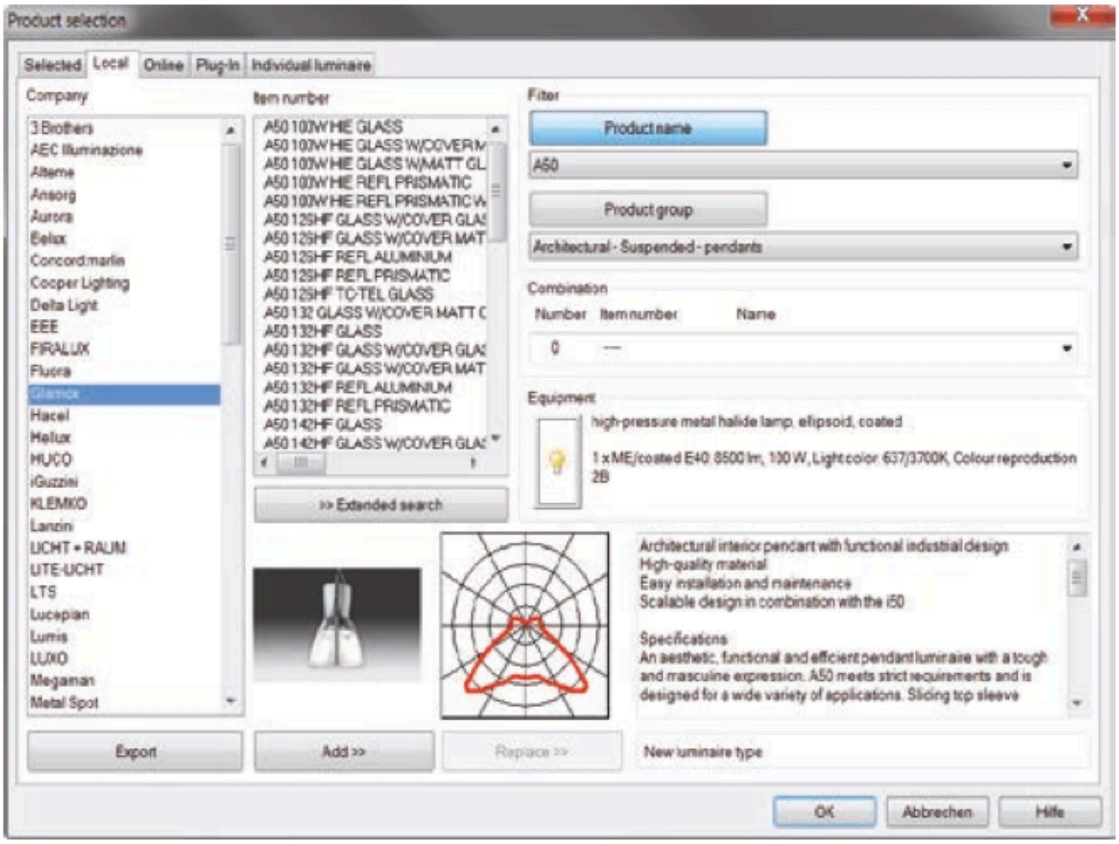


Figure 32: Screenshot of the selection of luminaires in ReluxPro

Supplier, site, contact, last version, cost

ReluxPro [www.relux.com] has been developed by Relux Informatik AG. The last officially released version is Version 2014.2. ReluxPro is part of ReluxSuite, which comprises also ReluxSensor, ReluxOffer and ReluxEnergy. The ReluxSuite is free of charge and available on the homepage of Relux. The manufacturers of luminaires have to pay an annual fee to be in the ReluxPro database locally or online [www.relux.net].

Functions

ReluxPro is a user-friendly interface that provides an easy-to-use yet powerful 2D and 3D import feature for the architectural plans and a 3D modeler. ReluxPro has an important luminaire database that allows defining the position of luminaires in the building and thanks to its fast rendering engine (based on radiosity calculations), it delivers visualization results in a short time.

ReluxPro also includes the calculation of illuminance levels. For each of the building zones, the calculated illuminance levels can be obtained together with the uniformities g1 and g2. The ray-tracing engine included in ReluxPro is a powerful tool for predicting the daylight penetration in buildings. So it is possible to obtain daylight factors in the rooms of the building and optimize the use of daylight. The ray-tracing engine can also calculate luminance and illuminance values. There are twenty-six language options.

Design Stage, Users

Professionals of the building construction sector, such as architects and lighting designers familiar with computer design tools.

Description Procedure

ReluxPro includes 3D modelling functionality which is manageable and very easy. The way to deal with 3D Models in ReluxPro is to import the 2D architectural plans and build the third dimension on top of it. The definition of the building is first determined with its internal partitions in different rooms. In a further step, these rooms can be fitted with furnishings and luminaires taken from a vast database. Window openings can be defined in the walls and likewise other elements like doors.

Results

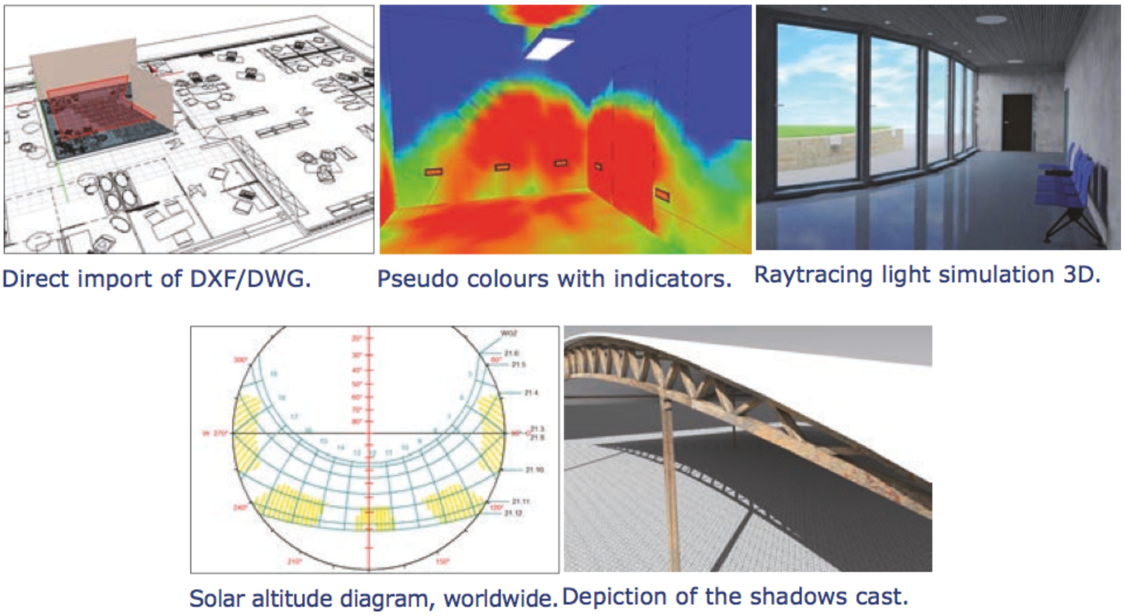


Figure 33: Screenshot of the interface of ReluxPro

To control the consistence of the 3D building model, it is useful to use the existing visualization functionality. The results of the rendering can be exported as .jpg, .bmp, and HDR image files for external usage.

Import/export

The 2D drawing file import function of ReluxPro contains the import of vector files like .dxf or .dwg as well as images like .bmp, .jpg, .wmf. After simulation, ReluxPro displays the result output optionally as graph, grid or tables, which later can be exported to clip board or file as .csv or .bmp. Several or single scenes can be exported into .dxf or .dwg formatted files including installed luminaires and calculation result. The report generation with export functionality to MS Word (.doc) is still under development. The internal data management will be improved as well in the future. At the moment, it is possible to export a .csv report file containing all information about the building model (volume, areas, area of built envelope, and zone data like elements, constructions and users activity definitions). The simulation output data can be exported separately.

References

www.relux.com

5.12. Velux Daylight Visualizer

Source: N. Roy / Public Affairs & Sustainability / VELUX Group, Denmark

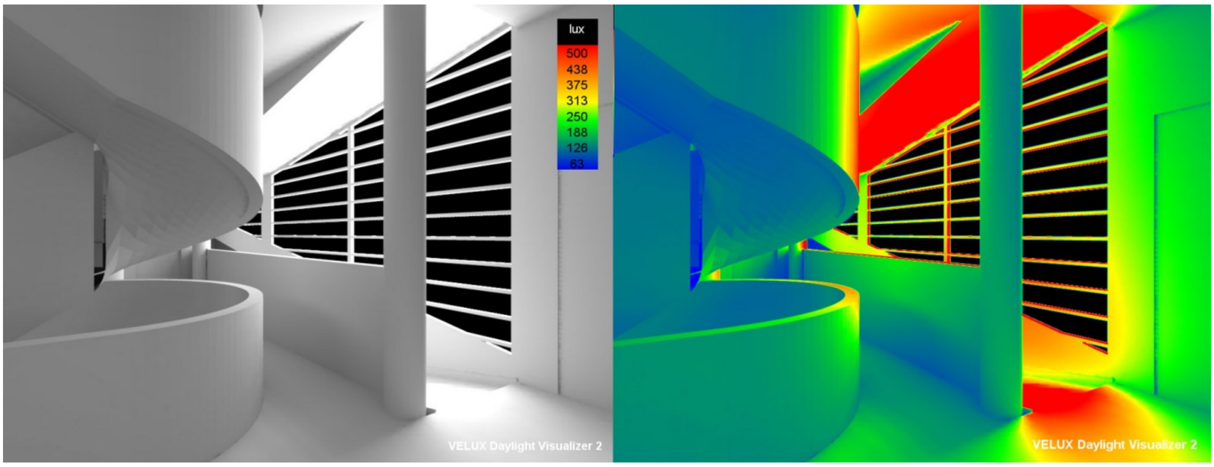


Figure 34: Illuminance rendering of Villa Savoye by Le Corbusier © Arkitekten Forlag

Supplier, site, contact, last version, cost

VELUX Daylight Visualizer [http://viz.VELUX.com/] is developed by Luxion in collaboration with the VELUX Group. The last officially released version is 2.6.7, which was published in May 2013 and is available for both Windows and MAC OS. The program is free and is published under a freeware license.

Functions

VELUX Daylight Visualizer is a professional simulation tool for the analysis and visualization of daylight conditions in buildings of any scale, including residential, commercial, institutional and industrial buildings. It is capable to simulate illuminance, luminance and daylight factor levels for all the 15 sky types defined by CIE.

The intuitive user interface of the program makes it accessible to new users and experienced users of lighting simulation tools, and can reduce the amount of time needed to perform daylight analysis. An easy-to-use embedded 3D modeller makes it possible for all users to create a wide range of rooms into which daylight conditions can be studied. A 3D importer allow users to import 3D models from the most popular CAD applications such as Autocad, Revit and Sketchup, which makes it possible to use 3D models that can already be available and more detailed.

Simulation output includes photo-realistic images which can be converted to false colour or iso-contour images, as well as numerical values. Users can generate a report with simulation results presenting the daylight performance by zone for each room/space in the building. In addition to still images, the program can be used to capture animations of the course of sunlight.

The program is available in 8 different languages: English, French, German, Spanish, Italian, Polish, Russian and Japanese.

VELUX Daylight Visualizer has been validated against CIE 171:2006: Test Cases to Assess the Accuracy of Lighting Computer Program. The program passed all test cases dedicated to natural lighting calculations. The evaluation was performed in collaboration with ENTPE, l'Ecole Nationale des Travaux Publics de l'Etat in France.

Design Stage, users

VELUX Daylight Visualizer is used by architects and engineers to predict and document daylight levels and appearance of a space prior to realization of the building design. The program can be used in the very early stage of the design to plan the availability and distribution of daylight in buildings, as well as in the later stage to show the appearance of daylight and validate the daylight performance of the final design. VELUX Daylight Visualizer is also used in several schools and universities to teach daylighting.

Description Procedure

VELUX Daylight Visualizer includes a 3D modeller which is very easy to use and capable of creating a wide range of room/building models in which both facade and roof windows (and doors) can be inserted. The 3D modeller makes it possible for people without the skills to create 3D models to make daylight analysis.

VELUX Daylight Visualizer is also capable to import 3D models directly from the most popular CAD programs such as Autocad, Revit and Sketchup among others. The supported file formats are *.dxf, *.dwg, *.skp and *.obj.

Results

The rendering method is based on bidirectional Monte Carlo ray tracing with photon mapping (irradiance caching) and uses the Fresnel equations to describe the properties of surfaces in the model. Results of the rendering or calculation can be saved as standard images (*.jpg, *.png), high dynamic range images (*.exr) and numerical values.

Import/export

VELUX Daylight Visualizer can import 3D models from the most popular CAD applications used in architectural design, including Autocad, Revit and Sketchup with support for the file formats *dwg, *dxf, *skp and *.obj.

3D models created in Daylight Visualizer can be exported to the format *.epx for use in connection with VELUX Energy and Indoor Climate Visualizer.
Image-based simulation results can be exported to standard or high dynamic range image formats including *.jpg, *.png and *.exr.

Numerical simulation results can be exported to *.html format.

References

http://viz.VELUX.com/

6. SCHEME FOR THE COMPARISON OF THE TOOLS

In this section we propose a matrix to summarize the features of the tools presented before.

	3DS Max	DALEC	DAYSIM	DIALUX	DIALUX-EVO	DIAL+	DIVA for Rhino	FENER	GERONIMO	IES VE	LIGHTSOLVE	RADIANCE	RELUX Pro	VELUX Daylight Visualizer
GENERAL INFORMATION														
Graphical User Interface	x	x		x		x	x	x	x	x	x		x	x
CAD Import	x			x			x			x	x	x	x	x
3D Modeler	x			x		x	x			x			x	x
3D Rendering	x			x			x		x	x	x	x	x	x
Radiance calculation		x				x	x	x	x	x	x	x	x	
Radiance 3phase calcualtion		x					x	x						
Daysim							x							
Photon mapping											x	x		x
TARGET														
Suited for architects	x	x				x	x	x	x	x	x		x	x
Suited for electric engineers		x	x			x				x		x	x	
Suited for HVAC engineers		x				x				x			x	
Suited for early design		x				x	x		x	x	x	x		x
Suited for detailed design	x		x				x	x	x	x	x	x	x	x
DAYLIGHTING														
Daylight factor values	x		x	x		x	x	x	x	x	x	x	x	x
Daylighting autonomy		x	x			x*	x	x+*	x*	x	x	x		
Sensible to Orientation	x	x	x			x	x	x	x	x	x	x		x
Climate file based simulation	x	x	x			x	x	x	x	x	x	x		
Illuminance values	x	x	x	x			x	x	x	x	x	x	x	x
Luminance values	x	x					x	x	x	x	x	x	x	x
Glare calculation		x	x				x	x	x	x	x	x	x	
Possibility to describe Fins /Overhang (fixed)	x	x	x	x		x	x	x		x	x	x	x	x
Possibility to describe shading devices (movable)		x	x			x	x	x*		x		x	x	x
Possibility to describe outdoor obstructions	x	x	x	x		x	x	x		x	x	x	x	x
ELECTRIC LIGHTING														
Manual input of luminaires				x		x				x		x		
Native data base of luminaires		x								x			x	
Possibility to import luminaires (IES, Eulumdat, …)				x		x	x			x		x	x	
Calculation of Illuminance values		x		x		x	x			x		x	x	
Calculation of Luminance values							x			x		x	x	
Calculation of annual electricity consumption		x	x			x	x	x					x	
Glare calculation				x			x			x		x	x	
ADVANCED FEATURES														
Possibility to handle BSDF datasets		x			x		x	x	x			x	x	x
Integration of daylighting and thermal simulations		x				x*	x	x*		x				
Spectral capabilities									x			x		
Scripting							x	x				x		

Table 2: **Summary of tool features**

The features are listed and detailed hereafter:
For each of the topics described hereafter, the possible choices are as follows:

	The tool cannot be applied
X	The tool is capable to provide a result
?	Unsure

GENERAL INFORMATION

- Graphical User Interface
  The tool includes its own graphical user interface
- CAD Import
  The tool allows importing CAD files
- 3D Modeller
  The tools allows to build and visualize a 3D model
- 3D Rendering
  The tools allows to produce a physically correct 3D rendering (luminances)
- Radiance Calculation
  The tool uses Radiance as simulation engine
- Radiance 3-phase Calculation

The tool uses the 3-phase method within RADIANCE as simulation engine

- Daysim
  The tool uses Daysim as simulation engine
- Photon mapping
  The simulations are made with photon mapping algorithms

TARGET

- Suited for architects
- Suited for electric engineers
- Suited for HVAC engineers
  The tool can be used within the day-to-day practice of the corresponding specialist
- Suited for early design
  The tool gives quick answers and is able to handle rough data.
- Suited for detailed design
  The tool gives detailed answers and is able to handle precise data (geometry & photometry).

DAYLIGHTING

- Daylight factor values
  The tool calculates DF values on the work plan.
- Daylighting autonomy
  The tool provides one of the following values:
  Diffuse Daylight Autonomy: Symbol "x"
  Dynamic Daylighting Autonomy: Symbol "x+"
  Useful Daylight Illuminance: Symbol "x++"
- Sensible to Orientation
  The tool gives different results
- Climate file based simulation
  The tool uses Climatic data to calculate for each hour, the indoor illuminance
- Illuminance values
  The tool calculates indoor illuminance values in relationship to outdoor specific sky conditions
- Luminance values
  The tools calculates luminance values according to the position of the observer, and taking into account glossy or specular surfaces
- Glare calculation
  The tool calculates one of the following glares indexes: DGP, UGR, GI, CGI1, CGI2, DGR
- Possibility to describe Fins /Overhang (fixed)
  The tools allow you to describe fixed shading devices
- Possibility to describe shading devices (movable)
  The tool allows you to describe movable blinds with specific scenarios for automation
- Possibility to describe outdoor obstructions
  The tools allow the description of outdoor obstructions (close environment like buildings and trees, as well as far obstructions like ills or mountains)

ELECTRIC LIGHTING

- Manual input of luminaires
  The tools allow describing generic luminaire (no specific product).

- Native data base of luminaires
  The tool includes a luminaire database (real products from the market)
- Possibility to import luminaires (IES, Eulumdat, etc.).
  The tool can use downloaded data from existing luminaires (real products from the market)
- Calculation of Illuminance values
  The tool calculates indoor illuminance values due to electric lighting
- Calculation of Luminance values
  The tools calculates luminance values according to the position of the observer, and taking into account glossy or specular surfaces
- Calculation of annual electricity consumption
  The tool estimates the annual energy consumption due to electric lighting according to the daylight contribution.
- Glare calculation
  The tool calculates one of the following glares index: UGR, GI, CGI1, CGI2

ADVANCED FEATURES

- Possibility to handle BSDF datasets
- Integration of daylighting and thermal simulations
- Spectral capabilities
  The tool allows realizing specific wavelength simulations
- Scripting

7. APPROPRIATENESS OF THE TOOLS ON TEST-CASES

7.1. Description of the case study for lighting simulations

Figure 35: Pictures of the Gymnase d'Yverdon before (left) and after refurbishment (right). The selected room is located on the first floor

Introduction

This section describes the characteristics of an existing classroom located in Western Switzerland (CH). This room belongs to the primary school of Gymnase d'Yverdon (Etat de Vaud - DFIRE - SIPAL, Service Immeuble Patrimoine et Logistique) and has been recently refurbished by CCHE-Architecture & Design, Lausanne.

Context: As in many refurbishment processes, daylighting was not the main driver here. Before refurbishment, this building had a very unfavourable energy balance with serious thermal comfort problems in winter (difficulty to maintain the indoor temperature within the comfort range) and in summer (overheating). In addition, the classrooms located in the corners were glazed on two façades, which was problematic regarding visual comfort.
In the refurbished project, all the classrooms are mono-oriented. This decision, which is mainly due to the willing of improving the thermal balance of the building, leads to a reduction of the daylight contribution but, on the other hand, this also contributes to improve the visual comfort of the occupant (less contrasts, suppression of counterview for the teacher).
After refurbishment, the building shows one of the best energy performance of all the buildings owned by Canton de Vaud.

The following information should be used to compare the results given by the different simulation tools (« Before » and « After » refurbishment).

Expected results from simulations

- **Daylight factor**
  - Max, Mean & Min DF values
  - Distribution on the workplane (map excluding a 50 cm perimeter band),
- **Daylight Autonomy 7:30 – 17:30 (UDI, DDA, etc.)**
  - Max, Mean & Min values
  - Distribution on the workplane (map)
- **Electric lighting**
  - Max, Mean & Min Illuminance values
  - Illuminance values on the workplane (map),
  - Uniformity g1 (Emin/Emean).
  - Annual energy consumption (if available)

- **Simulation conditions**
  The usage of the room is as follows:
  Occupancy:
  - Schedule: 7:30 - 17:30 / weekdays (Monday to Friday)
  - No lunch-break
  Months: July and August are not considered

Room characteristics

- **Location**
  Lat. 46.5 N. Long.: 6.4 E
- **Room Function**
  Classroom
  Workplane height: 0.80 m
  Illuminance level: 300 lux
  Working hours: 7:30 - 17:30
  Occupation ratio: 23.8 pers/room
- **Outdoor characteristics**
  Ground reflectance: 0.10
  Masks reflectance: 0.25
  Angular height of the obstruction masks (see Figure 1 and values in Table 3 below)

Orientation	N			E			S			W			N
Azimut (°)	-180	-150	-120	-90	-60	-30	0	30	60	90	120	150	180
Height(°)	10	12	6	20	26	26	24	17	9	6	5	6	10

Table 3: Values for the angular height of the outdoor obstruction masks (every 30°)

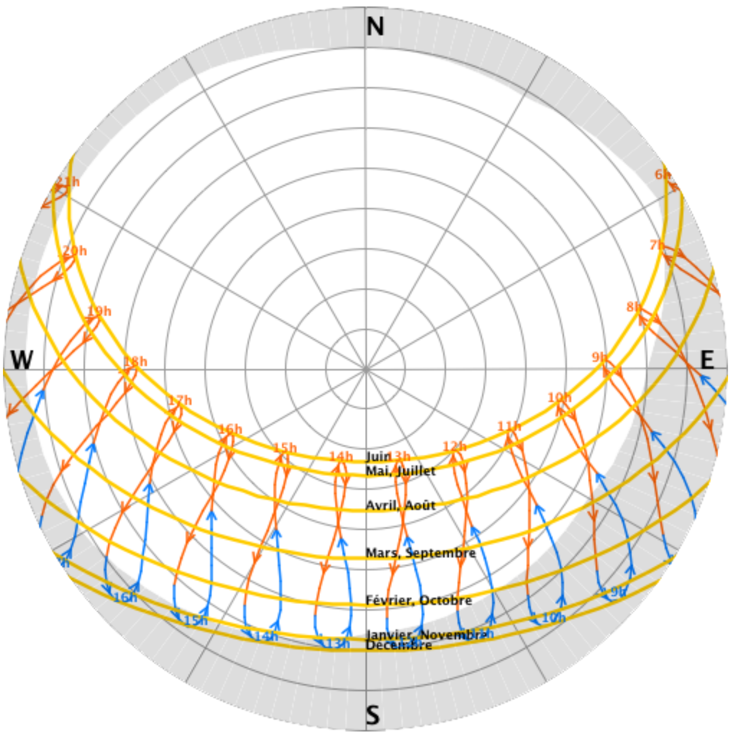


Figure 36: Schematic representation of the outdoor obstruction masks

7.1.1. Initial Situation

Photometry

Glazing transmittance: 0.80 ; Floor reflectance: 0.15 ; Walls reflectance: 0.35 ; Ceiling reflectance: 0.50; Pollution attenuation factor: 0.90

Luminaires

12 Opale diffuser 2x36 W, (cf Arcus.ldt & Arcus.ies files: Regent Arcus 79G.236.7),
4 rows of 3 luminaires, equidistant (cf. Figure 37).
Manual switch
Maintenance factor: 0.67 (3 years maintenance cycle)

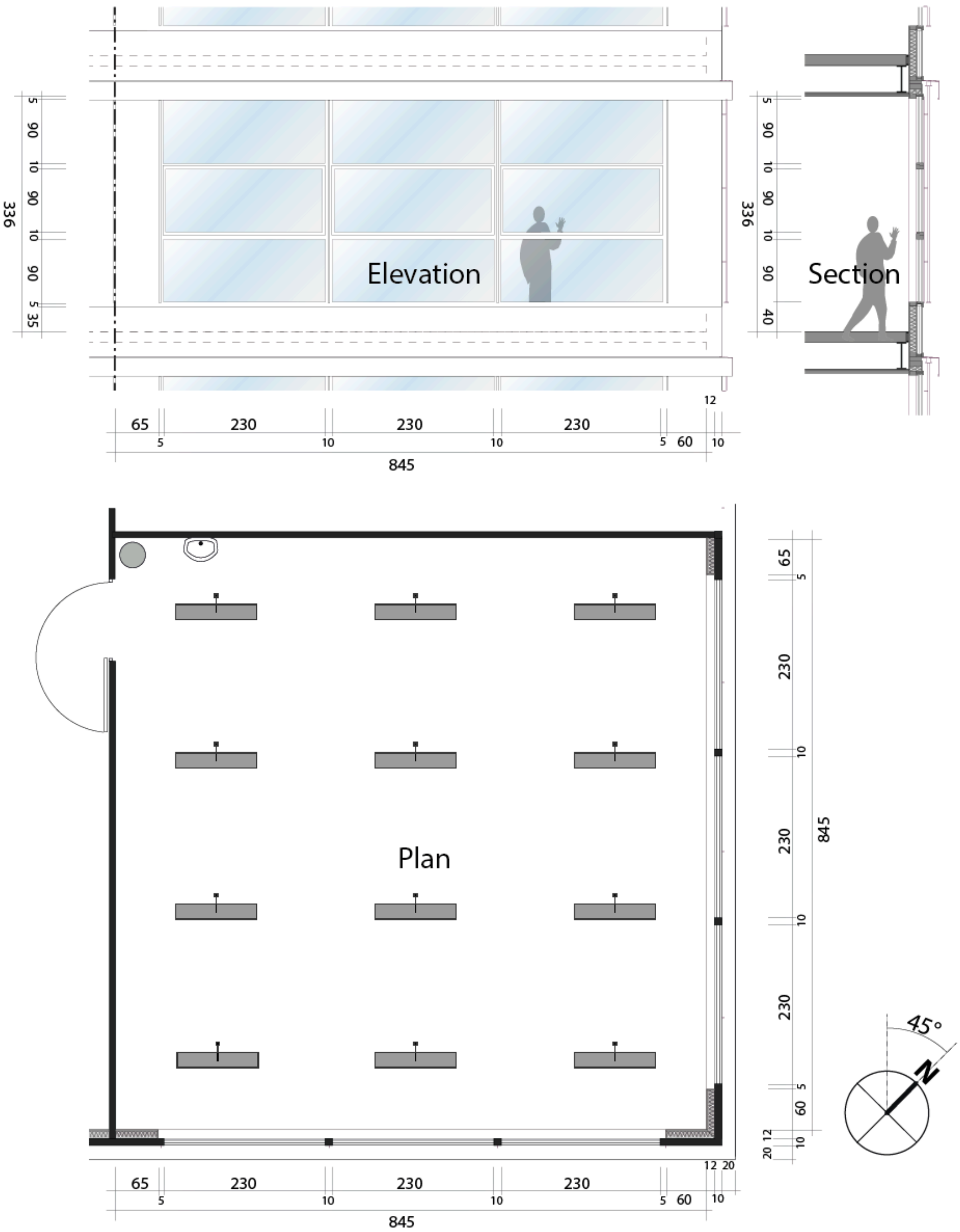


Figure 37: Geometric description of the initial situation

7.1.2. After Refurbishment

Photometry

Glazing transmittance: 0.73 ; Floor reflectance : 0.30 ; Walls reflectance : 0.65; Ceiling reflectance : 0.70; Pollution attenuation factor: 0.90

Luminaires

9 downlight luminaires 2x28 W, (cf Channel_1.5.ldt & Channel_1.5.ies files: Channel 1.5 93H41.2M12.7),
3 rows of 3 luminaires, equidistant repartition (Cf. Figure 38).
Maintenance factor: 0.67 (3 years maintenance cycle)

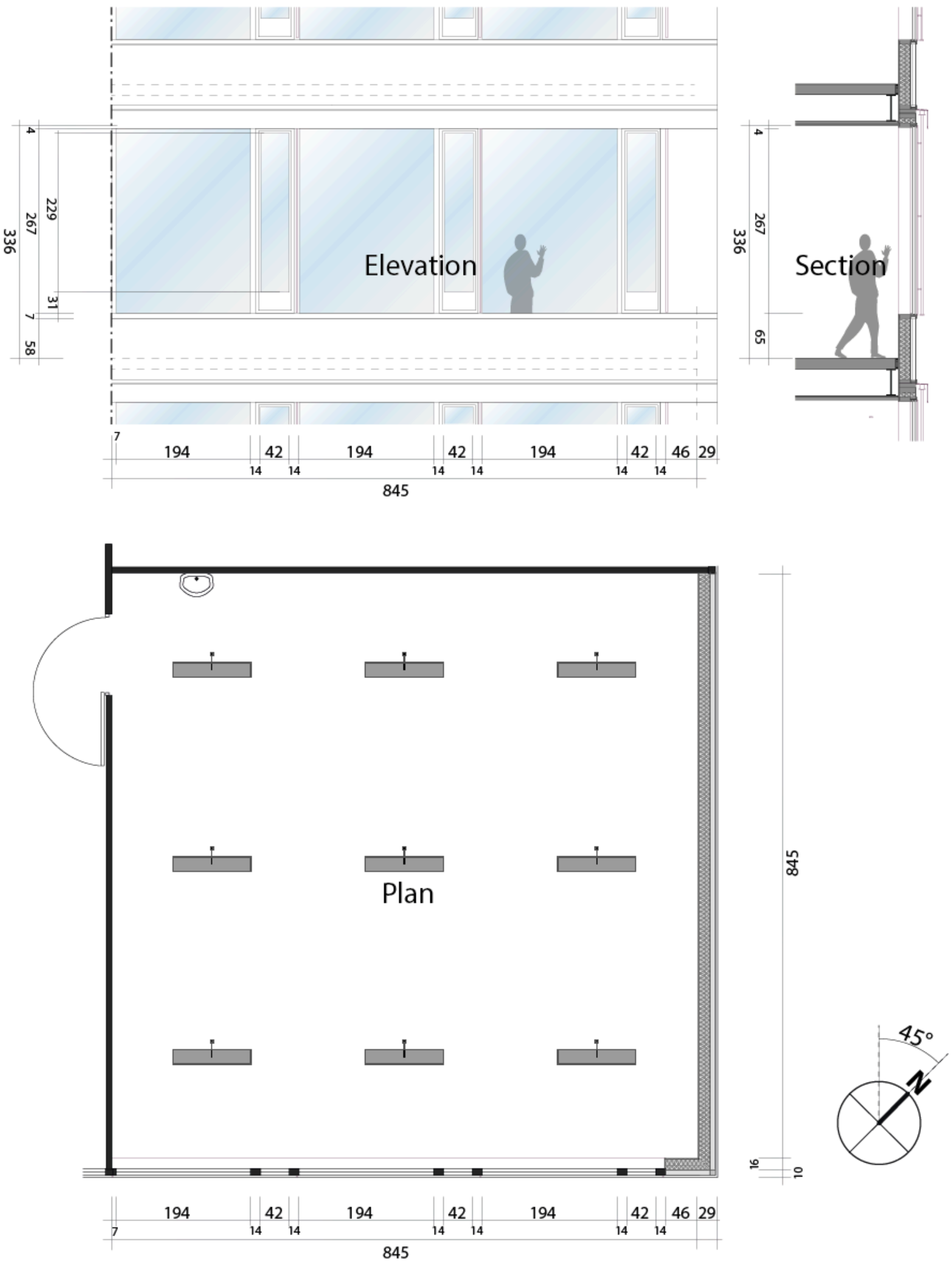


Figure 38: Geometric description of the new configuration

7.2. Results on test-case

This chapter focuses on daylight factor values and illuminance levels on the work plane due to electric lighting. The section starts with a short description of the Daylight Factor.

Daylight factor

Source: Bernard Paule

Short description

The **daylight factor** (%) is the ratio of internal light level to external light level and is defined as follows :
DF = Ei/Eo*100.
Where Ei = indoor illuminance, Eo = Outdoor illuminance.

The reference sky used for daylight factor calculations is Standard CIE overcast sky.
The typical values for DF can be analyzed as follow:

- DF < 2% : the influence of daylighting is low and the corresponding area is not adapted for permanent workplaces.
- 2% < DF < 5% : the influence of daylight is sensible and the corresponding area will take benefit from daylight up to 50% of the working hours.
- DF > 5% : the influence of daylight is high and the corresponding area will be self-sufficient during more than 50% of the working hours, but glare problems may occur.

Most standards dealing with environmental quality and energy efficiency, such as LEED, BREAM, CERTIVEA or DGNB, rely on daylight factor values (DF).

Classification *D*	***Daylight Penetration*** **(Access of the zone to daylight)**
D >= 3 %	Strong
3 % > *D* >= 2 %	Medium
2 % > *D* >= 1 %	Weak
l < *D* %	None

Table 4: Daylight penetration as a function of the Daylight Factor [3]

Limits

This approach does not take into account the direct component and is not sensible to climate and orientation. Furthermore, DF is not an intuitive notion and may hardly be used by non-specialists.

References

[1] ASE, Association Suisse des Electriciens Eclairage intérieur par la lumière du jour Association Suisse des Electriciens, Norme Suisse SN 418911, Zürich, 1989
[2] CIBSE Lighting Guide 10: Daylighting and window design, Year: 1999, ISBN 0-900953-98-5
[3] PrEN 15193: Energy performance of buildings — Energy requirements for lighting, CEN/TC 169, 2006.

7.2.1. 3DSMax Design

Source: Magali Bodart

INITIAL SITUATION

Daylight factor

Max: 20.9 %
Mean: 8.6 %
Min: 0.4 %

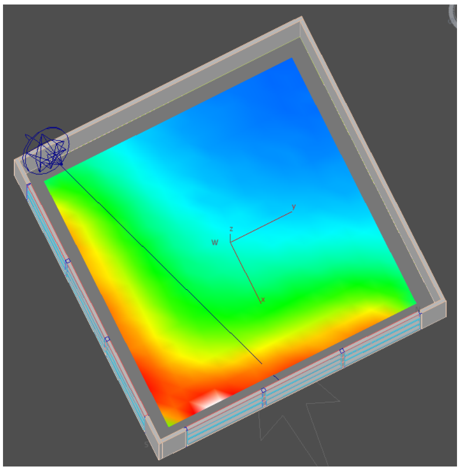


Figure 39: Daylight factor values for the initial situation

AFTER REFURBISHMENT

Daylight factor

Max: 19.9 %
Mean: 4.3 %
Min: 0.5 %

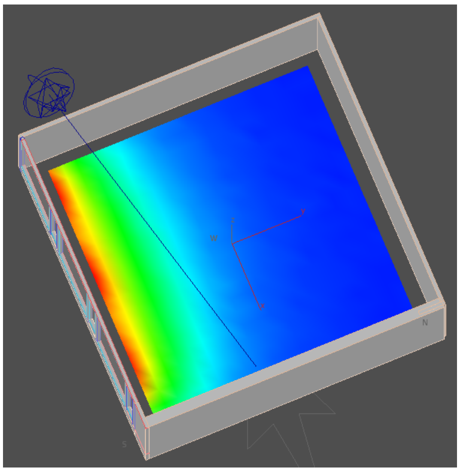


Figure 40: Daylight factor values for the refurbished situation

7.2.2. Daysim

Source: Magali Bodart

INITIAL SITUATION

Daylight factor

Max: 17.4 %
Mean: 7.6 %
Min: 1.9 %

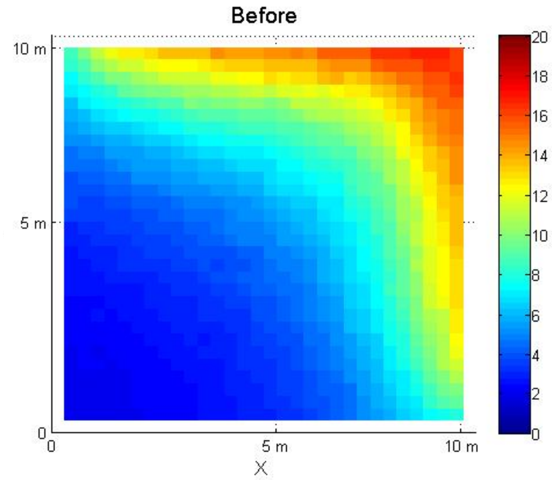


Figure 41: Daylight factor values for the initial situation

AFTER REFURBISHMENT

Daylight factor

Max: 15.4 %
Mean: 3.4 %
Min: 0.2 %

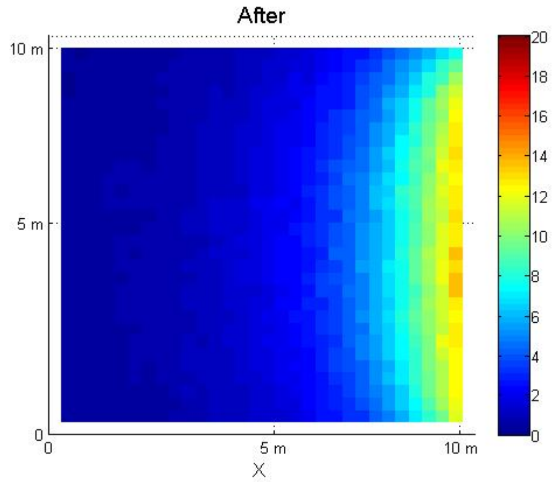


Figure 42: Daylight factor values for the refurbished situation

7.2.3. DIALUX

Source: Magali Bodart

INITIAL SITUATION

Daylight factor

Max: 25.0 %
Mean: 8.6 %
Min: 1.5 %

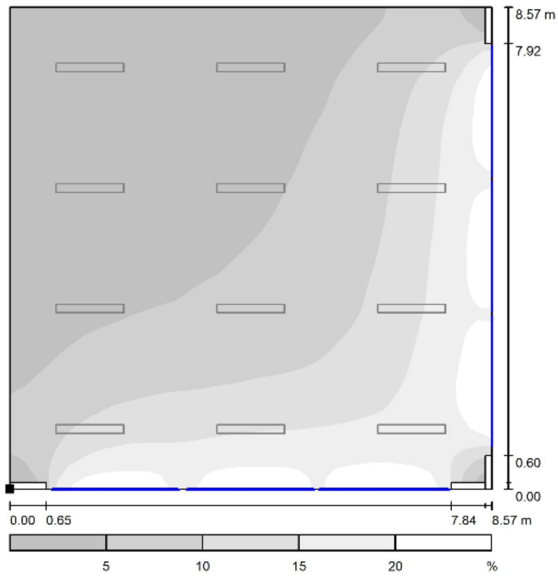


Figure 43: Daylight factor values for the initial situation

Electric lighting

Max: 396 lux
Mean: 324 lux
Min: 193 lux
Uniformity g1: 0.59

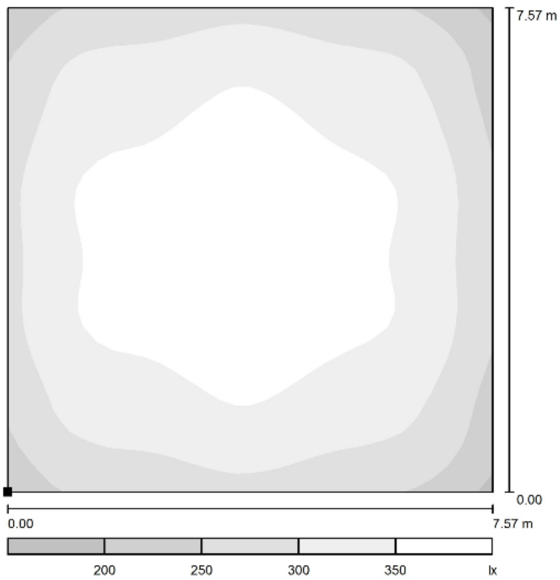


Figure 44: Illuminance values due to electric lighting in the initial situation

AFTER REFURBISHMENT

Daylight factor

Max: 18.0 %
Mean: 4.8 %
Min: 1.2 %

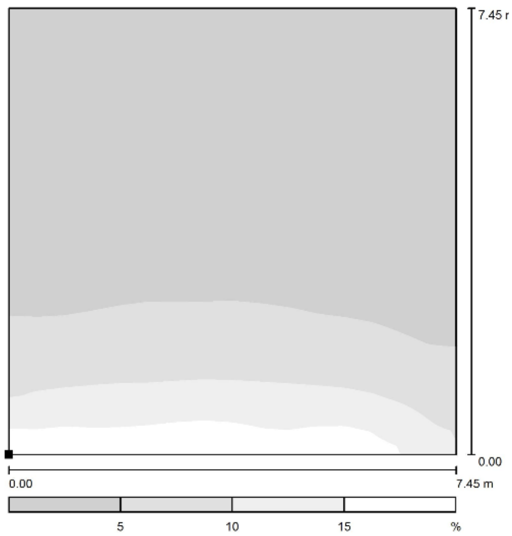


Figure 45: Daylight factor values for the refurbished situation

Electric lighting

Max: 435 lux
Mean: 330 lux
Min: 176 lux
Uniformity g1: 0.53

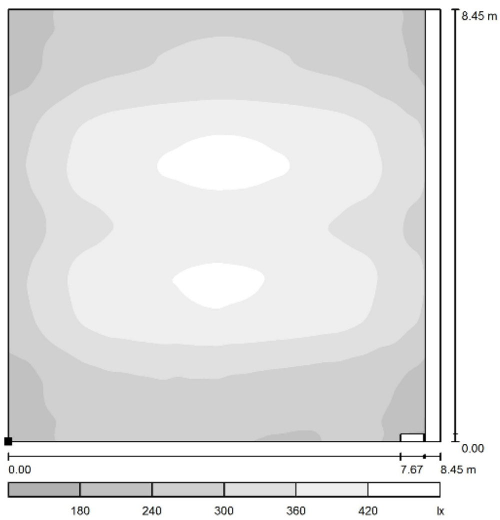


Figure 46: Illuminance values due to electric lighting in the refurbished situation

7.2.4. DIALUX-EVO

Source: Magali Bodart

INITIAL SITUATION

Daylight Factor (no obstructions)

Max: 18.5 %
Mean: 7.0 %
Min: 1.5 %

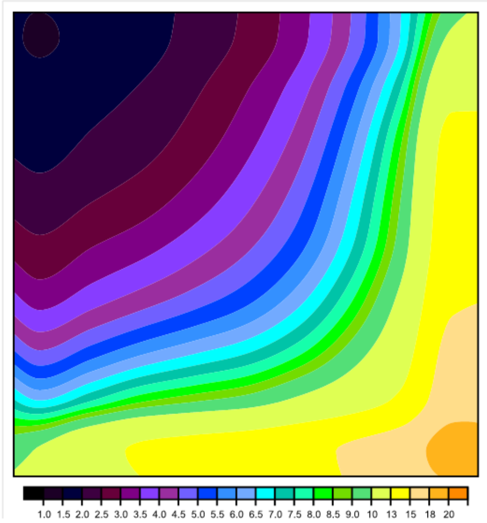


Figure 47: Daylight factor values for the initial situation

Electric lighting

Max: 406 lux
Mean: 335 lux
Min: 203 lux
Uniformity g1: 0.61

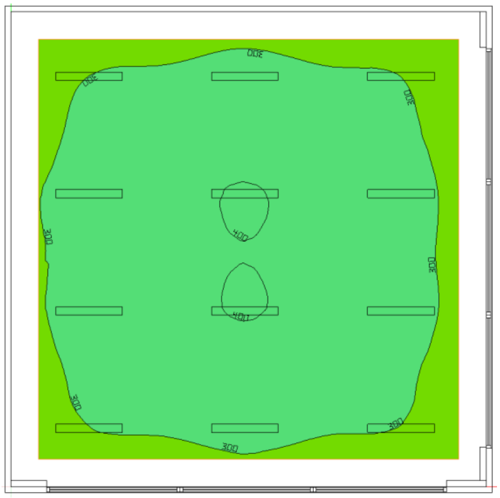


Figure 48: Illuminance values due to electric lighting in the initial situation

AFTER REFURBISHMENT

Daylight Factor– no obstructions

Max: 16.7 %
Mean: 5.7 %
Min: 1.8 %

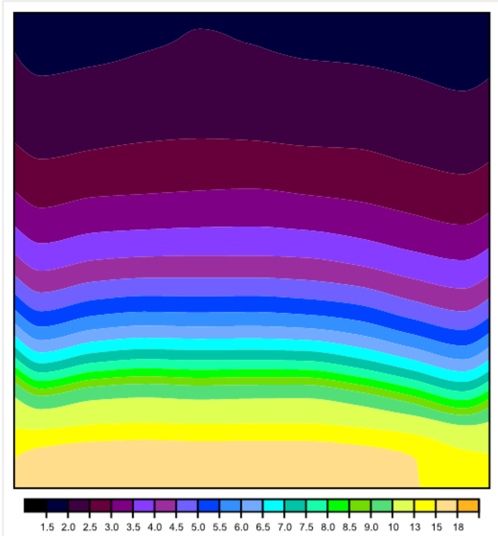


Figure 49: Daylight factor values for the refurbished situation

Electric lighting

Max: 436 lux,
Mean: 345 lux
Min: 205 lux
Uniformity g1: 0.59

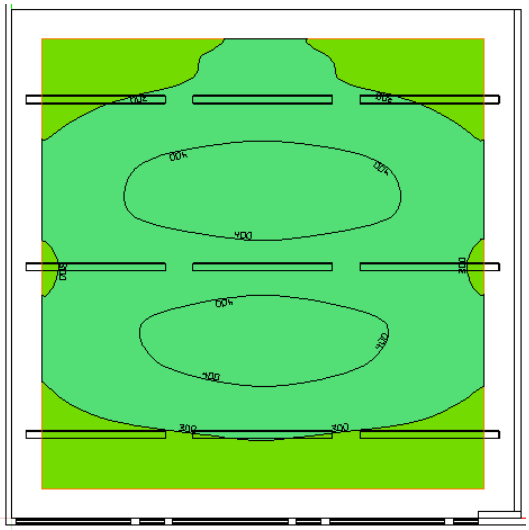


Figure 50: Illuminance values due to electric lighting in the refurbished situation

7.2.5. DIAL+Lighting

Source: Bernard Paule

INITIAL SITUATION

Daylight factor

Max: 20.0 %
Mean: 6.5 %
Min: 0.7 %

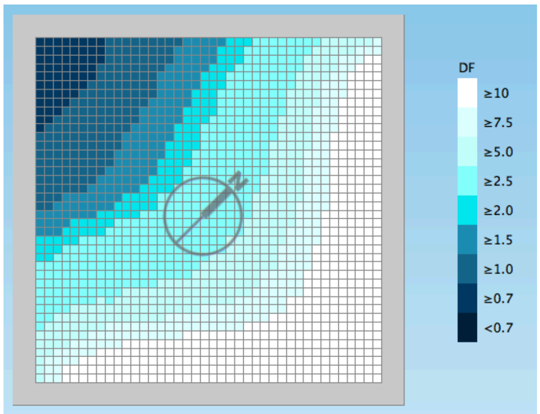


Figure 51: Daylight factor values for the initial situation

Electric lighting

Max: 400 lux
Mean: 331 lux
Min: 199 lux
Uniformity g1: 0.6
Annual energy consumption SIA 380/4*:
22.7 kWh/m2.y

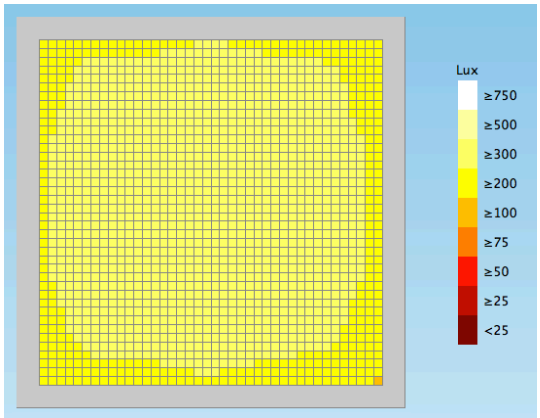


Figure 52: Illuminance values due to electric lighting in the initial situation

*SIA-380/4 is the Swiss standard for building energy evaluation. The annual electricity consumption is not simulated but calculated with simplified assumptions

AFTER REFURBISHMENT

Daylight factor

Max: 16.3 %
Mean: 3.3 %
Min: 0.5 %

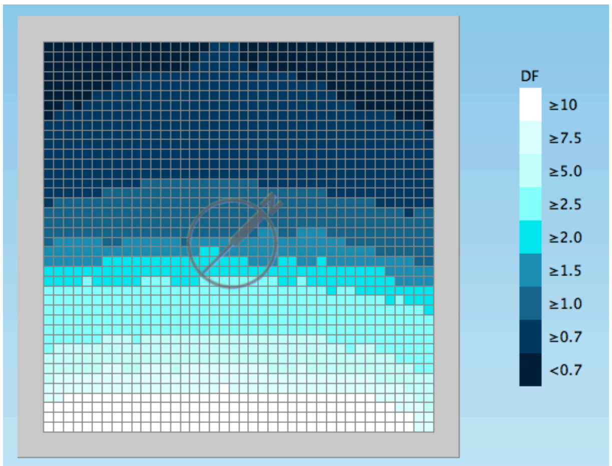


Figure 53: Daylight factor values in the refurbished situation

Electric lighting

Max: 442 lux
Mean: 343 lux
Min: 227 lux
Uniformity g1: 0.66
Annual energy consumption SIA 380/4: 11.4 kWh/m2.y

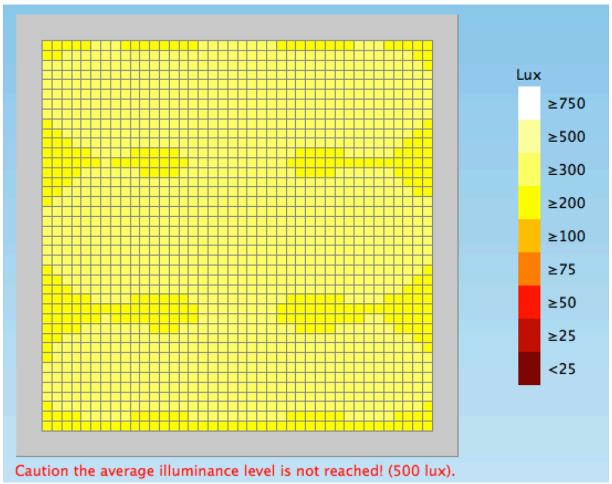


Figure 54: Illuminance values due to electric Lighting **i**n the refurbished situation

7.2.6. DIVA for Rhino

Source: Marie-Claude Dubois

Simulation Assumptions:

Site Description: The investigated building is located in GENEVA_CHE (46.25 N/ 6.13 W).
User Description: The total annual hours of occupancy at the work place are 3650.
Lighting Control: There is no electric lighting system specified for the scene.
Shading Control: There is no dynamic shading system in the scene.
Radiance rendering settings -ab 5 -ad 1000 -as 20 -ar 300 -aa 0.1

INITIAL SITUATION

Daylight factor

Max: 21.4 %
Mean: 8.5 %
Min: 1.0 %

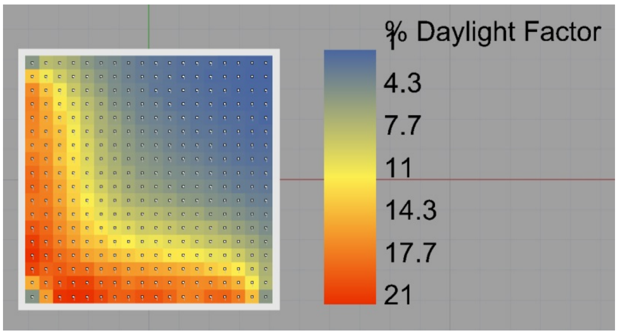


Figure 55: Daylight factor values – initial situation

Electric lighting

Max: 402 lux
Mean: 314 lux
Min: 170 lux
Uniformity g1: 0.54

Figure 56: Illustration of the luminance values due to electric lighting in the initial situation

AFTER REFURBISHMENT

Daylight factor

Max: 18.7 %
Mean: 4.5 %
Min: 0.8 %

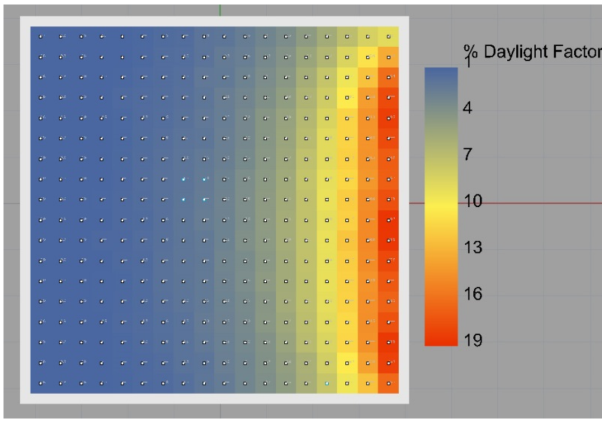


Figure 57: Daylight factor values in the refurbished situation

Electric lighting

Max: 433 lux
Mean: 333 lux
Min: 181 lux
Uniformity g1: 0.54

Figure 58: Illuminance values due to electric lighting in the refurbished situation

7.2.7. FENER

Source: Bruno Bueno

INITIAL SITUATION

Daylight factor

Max: 18.7 %
Mean: 8.4 %
Min: 2.1 %
Annual energy consumption: 3.3 kWh/m2.y
(Minimum annual lighting consumption assuming perfect manual switching)

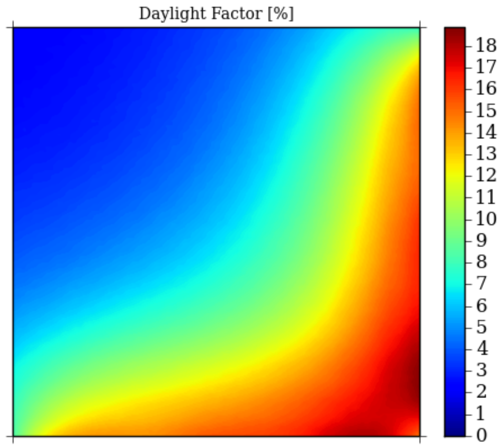


Figure 59: Daylight factor values in the initial situation

AFTER REFURBISHMENT

Daylight factor

Max: 14.1 %
Mean: 3.9 %
Min: 0.7 %
Annual energy consumption: 4.3 kWh/m2.y
(Minimum annual lighting consumption assuming perfect manual switching)

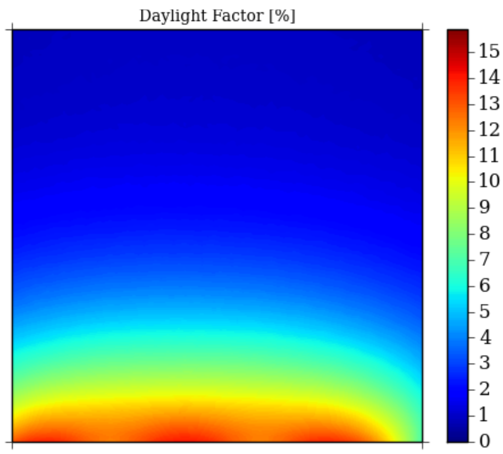


Figure 60: Daylight factor values in the refurbished situation

7.2.8. Geronimo

Source: Chantal Basurto & Jérome Kaempf

INITIAL SITUATION

Daylight factor

Max: 22.8 %
Mean: 9.4 %
Min: 1.8 %

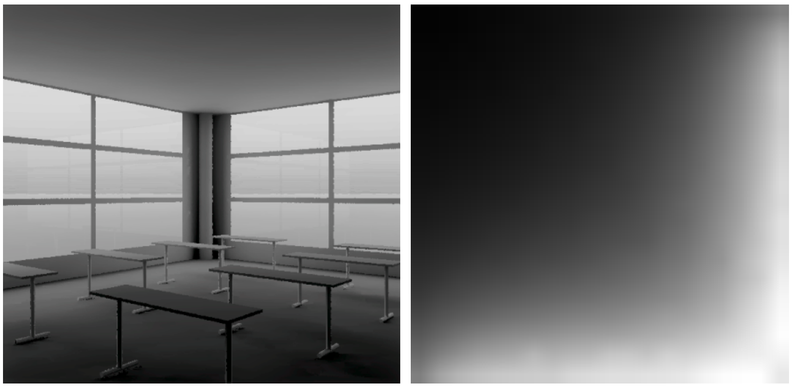


Figure 61: Daylight factor values in the initial situation

AFTER REFURBISHMENT

Daylight factor

Max: 17.8 %
Mean: 5.2 %
Min: 1.5 %

Figure 62: Daylight factor values in the refurbished situation

7.2.9. IES-VE

Source: Michael Jørgensen

INITIAL SITUATION

Daylight factor

Max: 20.3 %
Mean: 7.1 %
Min: 0.8 %

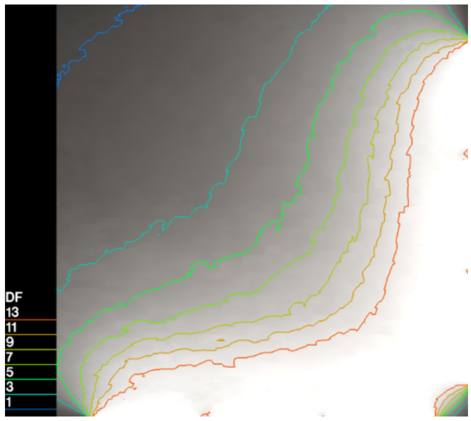


Figure 63: Daylight factor values in the initial situation

Electric lighting

Max: 389 lux
Mean: 287 lux
Min: 89 lux
Uniformity g1: 0.31

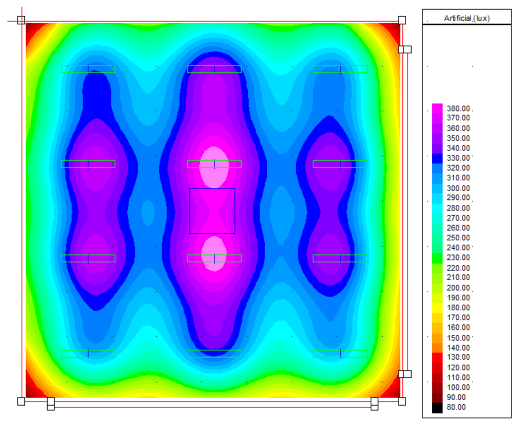


Figure 64: Illuminance values due to electric lighting in the initial situation

AFTER REFURBISHMENT

Daylight factor

Max: 14.8 %
Mean: 2.6 %
Min: 0.3 %

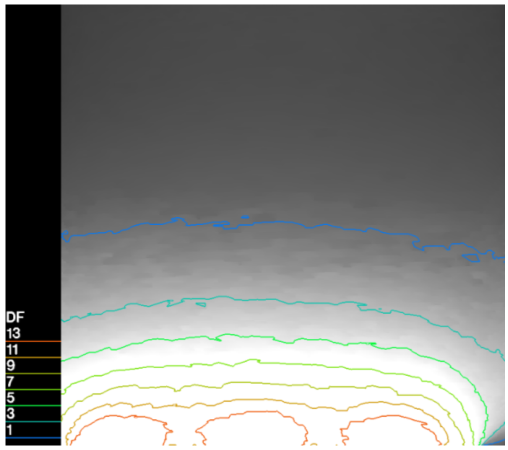


Figure 65: Daylight factor values in the refurbished situation

Electric lighting

Max: 445 lux
Mean: 319 lux
Min: 113 lux
Uniformity g1: 0.36

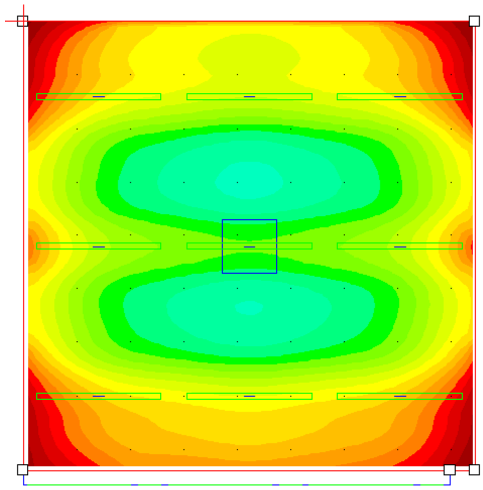


Figure 66: Illuminance values due to electric lighting in the refurbished situation

7.2.10. Lightsolve

Source: Jan Wienold

INITIAL SITUATION

Daylight factor

Max: 17.2 %
Mean: 8.5 %
Min: 2.0 %

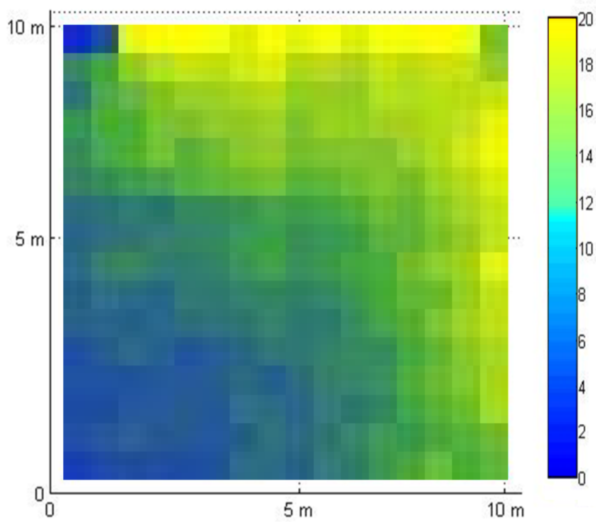


Figure 67: Daylight factor values - initial situation

AFTER REFURBISHMENT

Daylight factor

Max: 12.1 %
Mean: 3.3 %
Min: 0.5 %

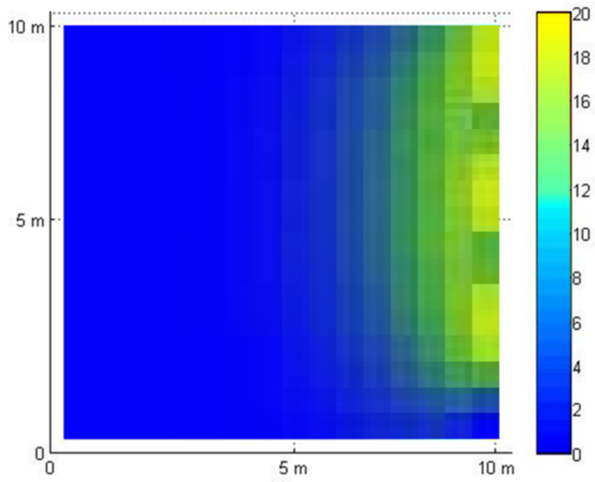


Figure 68: Daylight values - refurbished situation

7.2.11. Radiance

Source: David Geisler-Moroder

INITIAL SITUATION

Daylight factor

Max: 15.5 %
Mean: 5.5 %
Min: 0.7 %

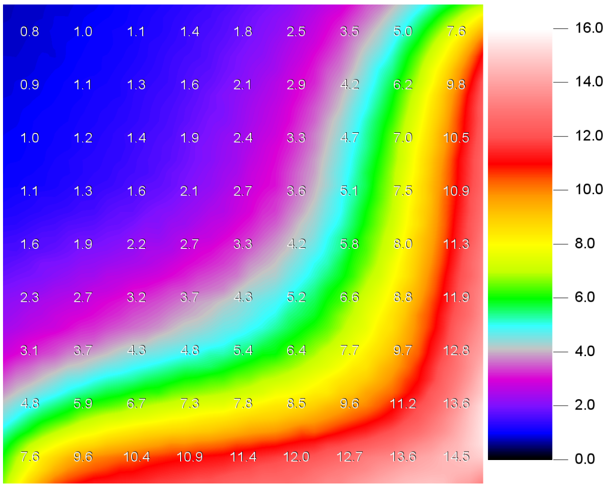


Figure 69: Daylight factor values in the initial situation

Electric Lighting

Max: 387 lux
Mean: 329 lux
Min: 214 lux
Uniformity g1: 0.65

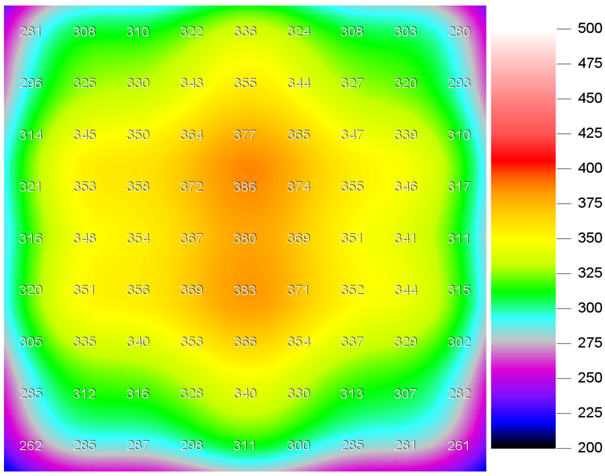


Figure 70: Illuminance values due to electric Lighting in the initial situation

AFTER REFURBISHMENT

Daylight factor

Max: 14.0 %
Mean: 3.2 %
Min: 0.6 %

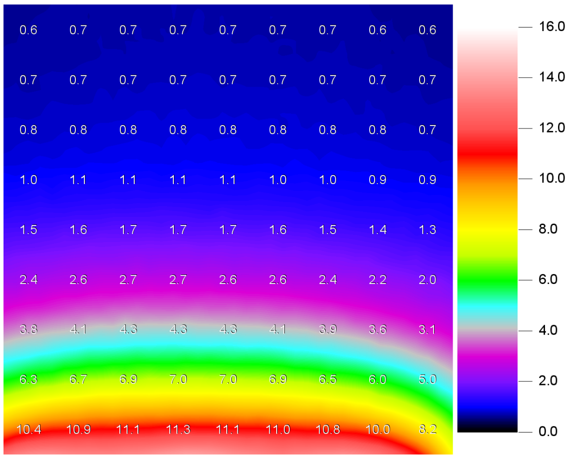


Figure 71: Daylight factor values in the refurbished situation

Electric Lighting

Max: 423 lux
Mean: 343 lux
Min: 199 lux
Uniformity g1: 0.58

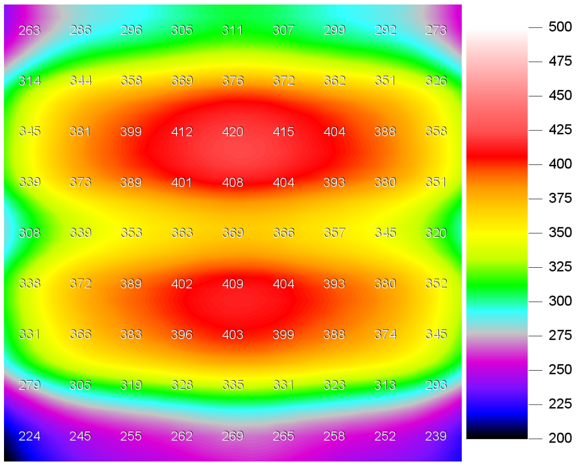


Figure 72: Illuminance values due to electric Lighting in the refurbished situation

7.2.12. ReluxPro

Source: Jérôme Kaempf

INITIAL SITUATON

Daylight factor

Max: 24.2 %
Mean: 9.9 %
Min: 1.5 %

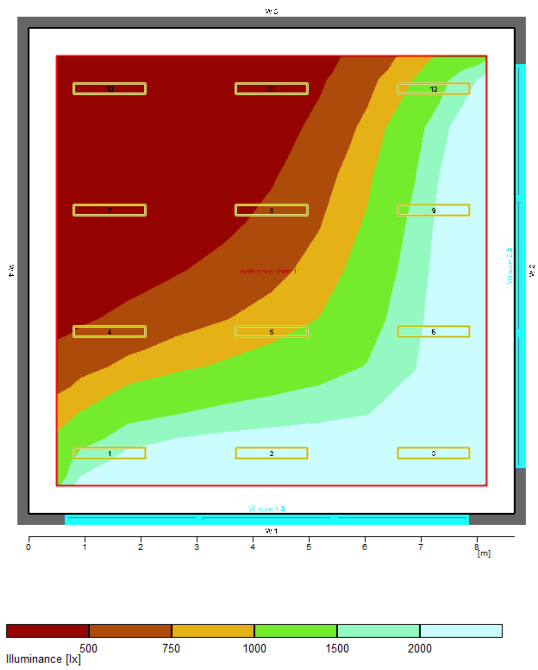


Figure 73: Daylight factor values in the initial situation

Electric lighting

Max: 384 lux
Mean: 323 lux
Min: 246 lux
Uniformity g1: 0.76.

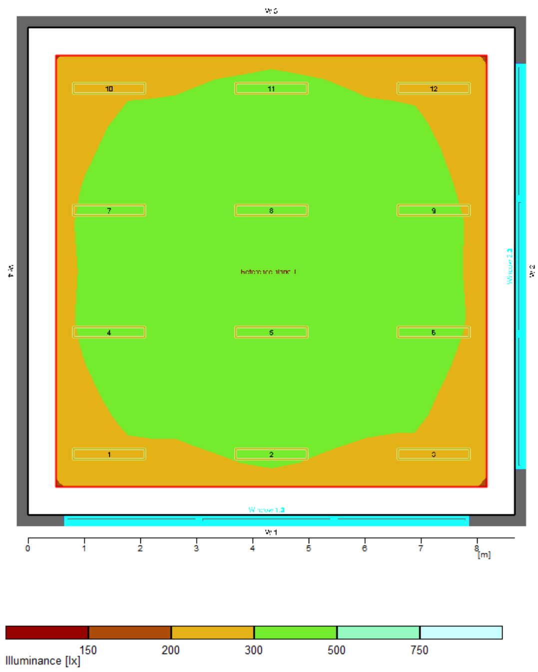


Figure 74: Illuminance values due to electric lighting in the initial situation

AFTER REFURBISHMENT

Daylight factor

Max: 19.9 %
Mean: 5.7 %
Min: 1.4 %

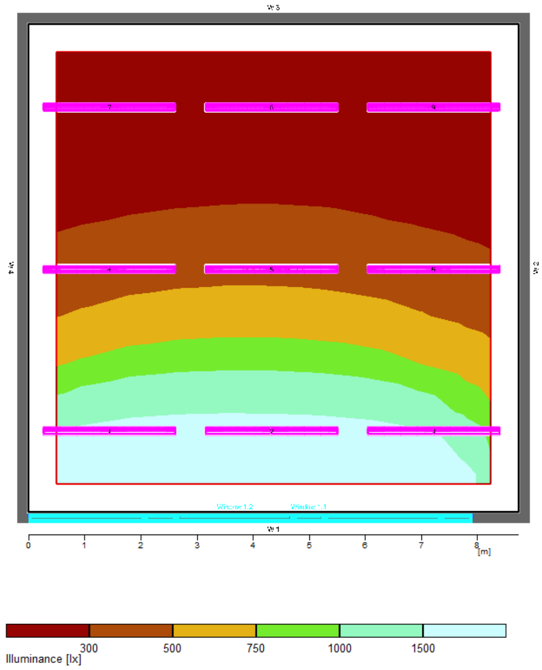


Figure 75: Daylight factor values in the refurbished situation

Electric lighting

Max: 418 lux
Mean: 335 lux
Min: 230 lux
Uniformity g1: 0.69.

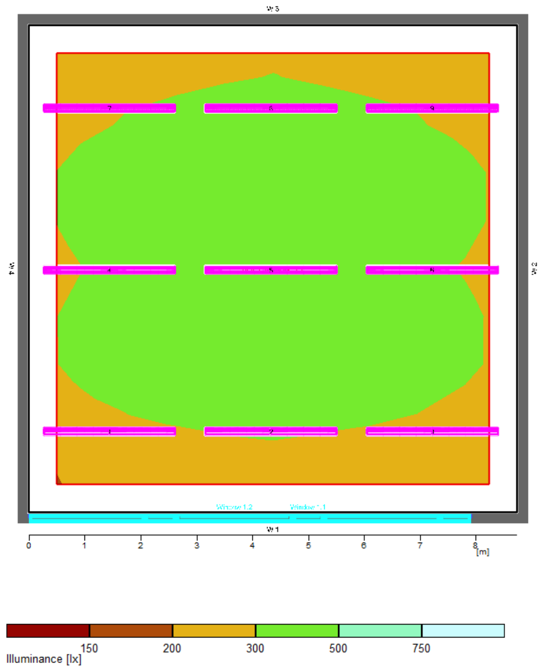


Figure 76: Illuminance values due to electric lighting in the refurbished situation

7.2.13. VELUX Daylight Visualizer

Source: Nicolas Roy

INITIAL SITUATION

Daylight factor

Max: 17.7 %
Mean: 5.7 %
Min: 0.4 %

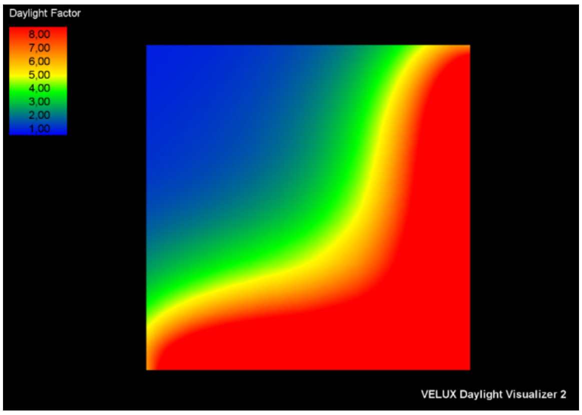


Figure 77: Daylight factor values in the initial situation

AFTER REFURBISHMENT

Daylight factor

Max: 16.7 %
Mean: 3.3 %
Min: 0.4 %

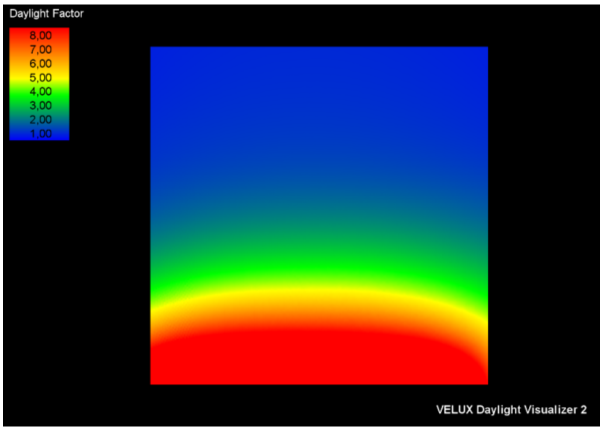


Figure 78: Daylight factor values in the refurbished situation

7.3. Analysis of the dispersion of the results

7.3.1. Daylight factor

	Daylight Factor (%)					
	Initial situation			After refurbishment		
	Max	Average	Min	Max	Average	Min
3DS Max	20.9	8.6	0.4	19.9	4.3	0.5
Daysim	17.4	7.6	1.9	15.4	3.4	0.2
Dialux	25.0	8.6	1.5	18.0	4.8	1.2
DIALux evo	18.5	7.0	1.5	16.7	5.7	1.8
DIAL+ Lighting	20.0	6.5	0.7	16.3	3.3	0.5
DIVA for Rhino	21.4	8.5	1.0	18.7	4.5	0.8
Fener	18.7	8.4	2.1	14.1	3.9	0.7
Geronimo	22.8	9.4	1.8	17.8	5.2	1.5
IES-VE	20.3	7.1	0.8	14.8	2.6	0.3
Lightsolve	17.2	8.5	2.0	12.1	3.3	0.5
Radiance	15.5	5.5	0.7	14.0	3.2	0.6
ReluxPro	24.2	9.9	1.5	19.9	5.7	1.4
Velux Daylight Visualizer	17.7	5.7	0.4	16.7	3.3	0.4
Median	20.0	8.4	1.5	16.7	3.9	0.6

Table 5 and Figure 79 show a summary of the results obtained on the case-study with the different tools for the daylight factor calculation. The corresponding dispersion is shown as Box-Plots in Figure 80 and Figure 81.

	Daylight Factor (%)					
	Initial situation			After refurbishment		
	Max	Average	Min	Max	Average	Min
3DS Max	20.9	8.6	0.4	19.9	4.3	0.5
Daysim	17.4	7.6	1.9	15.4	3.4	0.2
Dialux	25.0	8.6	1.5	18.0	4.8	1.2
DIALux evo	18.5	7.0	1.5	16.7	5.7	1.8
DIAL+ Lighting	20.0	6.5	0.7	16.3	3.3	0.5
DIVA for Rhino	21.4	8.5	1.0	18.7	4.5	0.8
Fener	18.7	8.4	2.1	14.1	3.9	0.7
Geronimo	22.8	9.4	1.8	17.8	5.2	1.5
IES-VE	20.3	7.1	0.8	14.8	2.6	0.3
Lightsolve	17.2	8.5	2.0	12.1	3.3	0.5
Radiance	15.5	5.5	0.7	14.0	3.2	0.6
ReluxPro	24.2	9.9	1.5	19.9	5.7	1.4
Velux Daylight Visualizer	17.7	5.7	0.4	16.7	3.3	0.4
Median	20.0	8.4	1.5	16.7	3.9	0.6

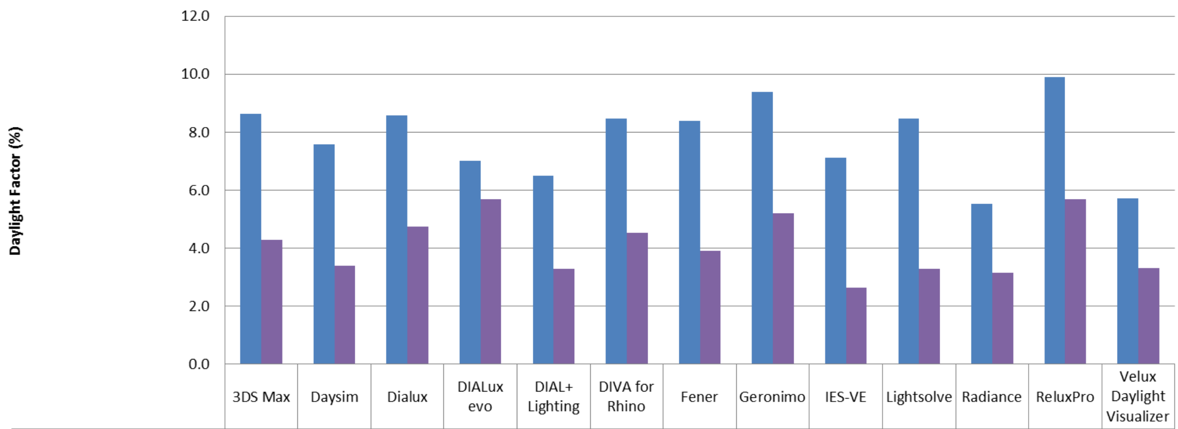
Table 5: Summary of the daylight factor values obtained by the different tools (red figures correspond to the highest value and blue ones to the lowest)

Considering that the glazed area has been divided by two in the refurbished case, and that the the CIE-overcast sky is uniformly distributed azimuth wise and, if we neglect the inter-

reflections in the room, we should have a ratio of ½ for the average values of the refurbished case compared to the initial situation. This is the general trend that we observe in

	Daylight Factor (%)					
	Initial situation			After refurbishment		
	Max	Average	Min	Max	Average	Min
3DS Max	20.9	8.6	0.4	19.9	4.3	0.5
Daysim	17.4	7.6	1.9	15.4	3.4	0.2
Dialux	25.0	8.6	1.5	18.0	4.8	1.2
DIALux evo	18.5	7.0	1.5	16.7	5.7	1.8
DIAL+ Lighting	20.0	6.5	0.7	16.3	3.3	0.5
DIVA for Rhino	21.4	8.5	1.0	18.7	4.5	0.8
Fener	18.7	8.4	2.1	14.1	3.9	0.7
Geronimo	22.8	9.4	1.8	17.8	5.2	1.5
IES-VE	20.3	7.1	0.8	14.8	2.6	0.3
Lightsolve	17.2	8.5	2.0	12.1	3.3	0.5
Radiance	15.5	5.5	0.7	14.0	3.2	0.6
ReluxPro	24.2	9.9	1.5	19.9	5.7	1.4
Velux Daylight Visualizer	17.7	5.7	0.4	16.7	3.3	0.4
Median	20.0	8.4	1.5	16.7	3.9	0.6

Table 5.



	3DS Max	Daysim	Dialux	DIALux evo	DIAL+ Lighting	DIVA for Rhino	Fener	Geronimo	IES-VE	Lightsolve	Radiance	ReluxPro	Velux Daylight Visualizer
Initial situation Average	8.6	7.6	8.6	7.0	6.5	8.5	8.4	9.4	7.1	8.5	5.5	9.9	5.7
After refurbishment Average	4.3	3.4	4.8	5.7	3.3	4.5	3.9	5.2	2.6	3.3	3.2	5.7	3.3

Figure 79: Summary of the results obtained with the different tools on the case-study

Figure 79 shows that for the initial situation, the biggest difference in the average illuminance value is found between the tools Radiance (5.5%) and ReluxPro (9.9%), their relative differences compared to the median value are respectively of -31.3% and +23.8%.
For the after refurbishment situation, the biggest difference in the average illuminance value is between IES-VE (2.6%) and Relux Pro (5.7%).

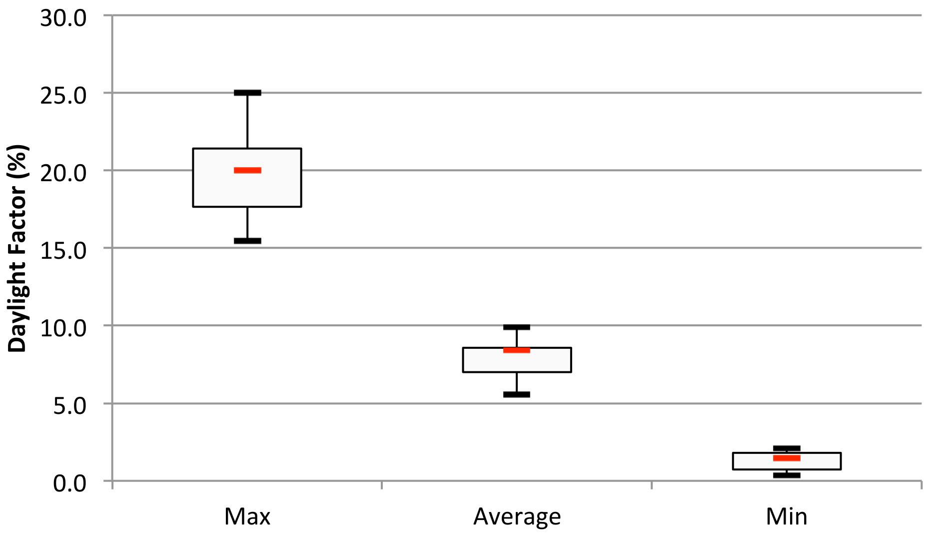


Figure 80: Daylight factor values in the initial situation

These differences are not negligible and this points out the fact that simulation results should always be considered as indicators and not as the truth. Even with the same calculation engine, for instance RADIANCE, considering different sets of simulation parameters leads to different results (such as with Geronimo and DIAL+). Looking at the distribution of the maximum daylight factor obtained with the different tools, we can notice that one tool is reaching a value of 25%, which we can obtain only nearby the window, indicating that the 50 cm perimeter band was probably not excluded in the simulation. The distribution of the minimum DF values is rather concentrated around the median value.

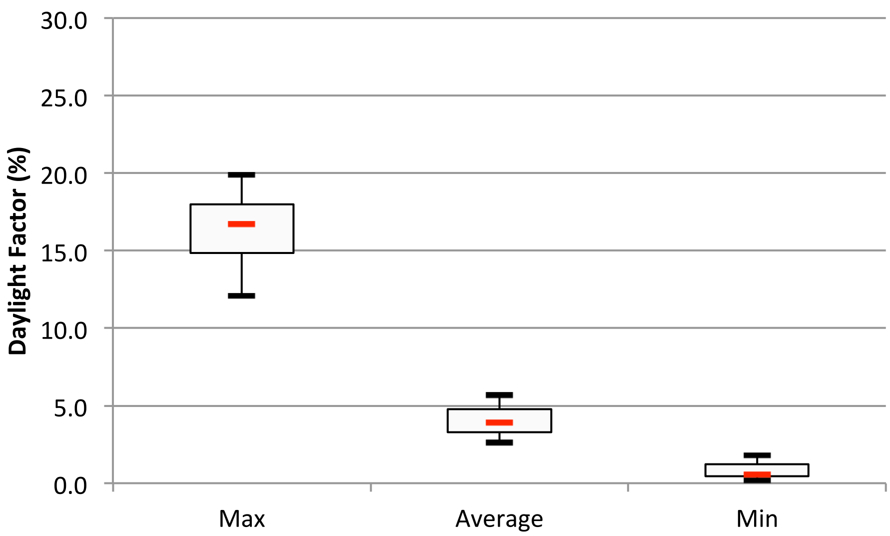


Figure 81: Daylight factor values in the refurbished situation

Regarding the maximum values, in both refurbished and initial cases, the important dispersion is also due to the facts that the tools do not use the same grid of points. For instance Geronimo uses a 20x20 grid unlike Dial+ which uses a 40x40 one. Indeed, a difference of a few centimetres of the point position near the windows can lead to important differences in daylight factor values. The same reason applies to the minimum daylight factor values of the grid of points.

7.3.2. Electric lighting

	Electric Lighting Illuminance (lx)							
	Initial situation				After refurbishment			
	Max	Average	Min	g1	Max	Average	Min	g1
3DS Max	N/A	N/A	N/A		N/A	N/A	N/A	
Daysim	N/A	N/A	N/A		N/A	N/A	N/A	
Dialux	396	324	193	0.60	435	330	176	0.53
DIALux evo	406	335	203	0.61	436	345	205	0.59
DIAL+ Lighting	400	331	199	0.60	442	343	227	0.66
DIVA for Rhino	402	314	170	0.54	433	333	181	0.54
Fener	N/A	N/A	N/A		N/A	N/A	N/A	
Geronimo	N/A	N/A	N/A		N/A	N/A	N/A	
IES-VE	389	287	89	0.31	445	319	113	0.35
Lightsolve	N/A	N/A	N/A		N/A	N/A	N/A	
Radiance	387	329	214	0.65	423	343	199	0.58
ReluxPro	384	323	246	0.76	418	335	230	0.69
Velux Daylight Visualizer	N/A	N/A	N/A		N/A	N/A	N/A	
Median	396	324	199	0.60	435	335	199	0.58

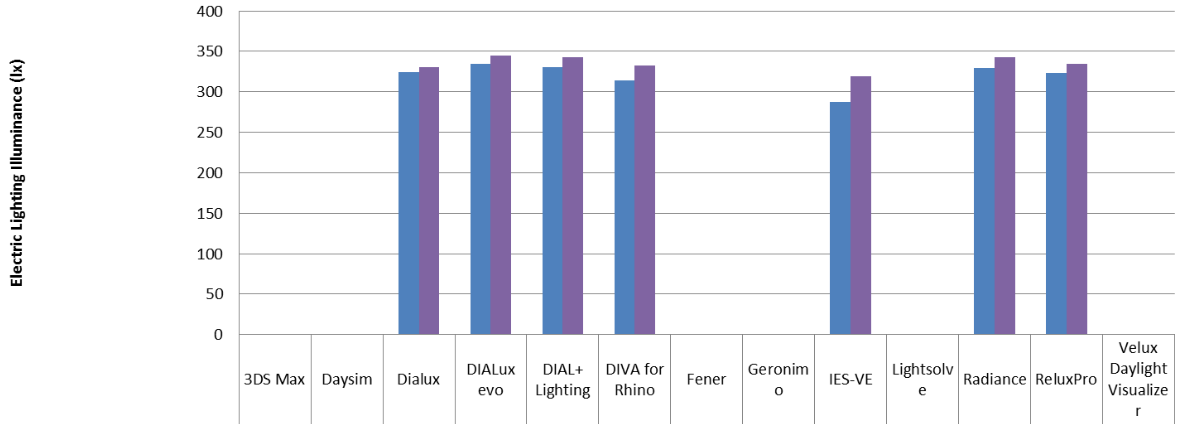
Table 6 and Figure 82 present a summary of the results obtained on the case-study with the different tools for the electric lighting illuminance. The corresponding dispersion is shown as Box-Plots in Figure 83 and Figure 84.

	Electric Lighting Illuminance (lx)							
	Initial situation				After refurbishment			
	Max	Average	Min	g1	Max	Average	Min	g1
3DS Max	N/A	N/A	N/A		N/A	N/A	N/A	
Daysim	N/A	N/A	N/A		N/A	N/A	N/A	
Dialux	396	324	193	0.60	435	330	176	0.53
DIALux evo	406	335	203	0.61	436	345	205	0.59
DIAL+ Lighting	400	331	199	0.60	442	343	227	0.66
DIVA for Rhino	402	314	170	0.54	433	333	181	0.54
Fener	N/A	N/A	N/A		N/A	N/A	N/A	
Geronimo	N/A	N/A	N/A		N/A	N/A	N/A	
IES-VE	389	287	89	0.31	445	319	113	0.35
Lightsolve	N/A	N/A	N/A		N/A	N/A	N/A	
Radiance	387	329	214	0.65	423	343	199	0.58
ReluxPro	384	323	246	0.76	418	335	230	0.69
Velux Daylight Visualizer	N/A	N/A	N/A		N/A	N/A	N/A	
Median	396	324	199	0.60	435	335	199	0.58

Table 6 : Electric lighting summary of the illuminance values obtained by the different tools (red figures correspond to the highest value and blue ones to the lowest)

	Electric Lighting Illuminance (lx)							
	Initial situation				After refurbishment			
	Max	Average	Min	g1	Max	Average	Min	g1
3DS Max	N/A	N/A	N/A		N/A	N/A	N/A	
Daysim	N/A	N/A	N/A		N/A	N/A	N/A	
Dialux	396	324	193	0.60	435	330	176	0.53
DIALux evo	406	335	203	0.61	436	345	205	0.59
DIAL+ Lighting	400	331	199	0.60	442	343	227	0.66
DIVA for Rhino	402	314	170	0.54	433	333	181	0.54
Fener	N/A	N/A	N/A		N/A	N/A	N/A	
Geronimo	N/A	N/A	N/A		N/A	N/A	N/A	
IES-VE	389	287	89	0.31	445	319	113	0.35
Lightsolve	N/A	N/A	N/A		N/A	N/A	N/A	
Radiance	387	329	214	0.65	423	343	199	0.58
ReluxPro	384	323	246	0.76	418	335	230	0.69
Velux Daylight Visualizer	N/A	N/A	N/A		N/A	N/A	N/A	
Median	396	324	199	0.60	435	335	199	0.58

Table 6 shows a rather high dispersion regarding homogeneity (g1). As a reminder, the European Norm EN 12464-1 requires that this value should be higher than 0.50 is surrounding area of the work plane. This is supposed to restrict the contrasts in the field of view. This relative dispersion between the results is probably due to the fact that for some simulations, the perimeter band of 50 cm has not been excluded, which leads to take into account lower illuminance values near the walls.



	3DS Max	Daysim	Dialux	DIALux evo	DIAL+ Lighting	DIVA for Rhino	Fener	Geronimo	IES-VE	Lightsolve	Radiance	ReluxPro	Velux Daylight Visualizer
Initial situation Average	0	0	324	335	331	314	0	0	287	0	329	323	0
After refurbishment Average	0	0	330	345	343	333	0	0	319	0	343	335	0

Figure 82: Electric lighting average illuminance values before and after refurbishment

Figure 82 shows that for the initial situation, the biggest difference in the average illuminance value is found between the tools IES-VE (287 lx) and DIAL+ Lighting (331 lx), their relative difference compared to the median value are respectively of -11.4% and +2.2%. Here again not removing the 50 cm perimeter band leads to decrease the average value. For the after refurbishment situation, the biggest difference is between DIVA for Rhino (300 lx) and DIAL+ Lighting (442 lx). It is worth noting that the spread in the case of electric lighting is relatively small compared to daylighting and remains below 15%.

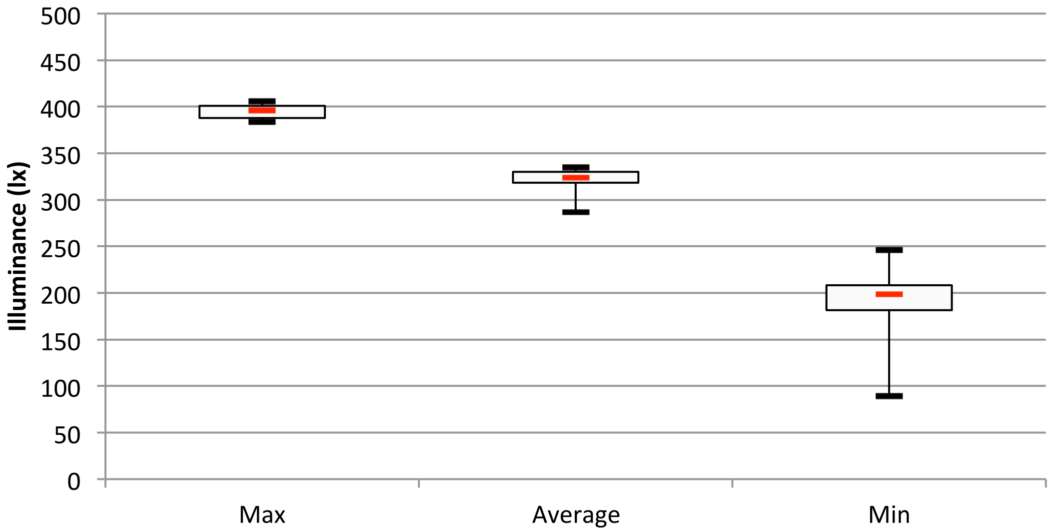


Figure 83: Electric lighting before refurbishment

Figure 83 shows that for the maximum value the dispersion is very low, which confirms that all the software produce similar figures on the workplane under the luminaires. Looking at the dispersion of the minimum values, this figure allows us to detect the problem with the perimeter band. The dispersion of the average value is therefore biased towards lesser values. Similar findings can be observed in Figure 84 for refurbished case.

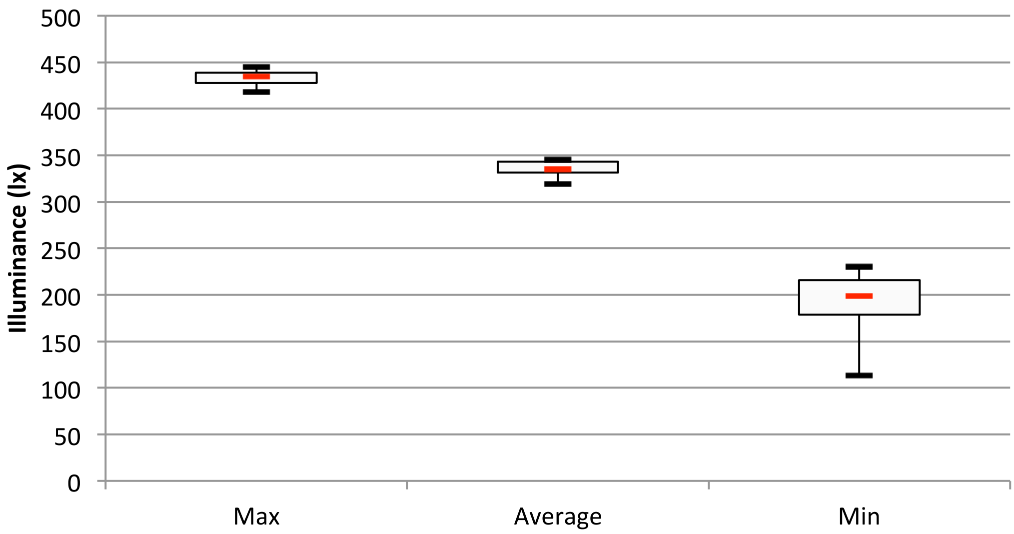


Figure 84: Electric lighting after refurbishment

7.3.3. Conclusions

The case-study shows that the dispersion between different expert users and tools (even the ones based on the same rendering engine RADIANCE) can be important for the daylight factor estimation. This indicates that even though the case-study was described with great care and handled by lighting experts, the end-users of such tools should not rely at 100 % on the simulation results. The daylight factor values are the simplest result for daylighting to compute and can be estimated by any tool in this study, however their uncertainty leads not to consider such dispersion study on the other lighting metrics presented in C4.
Finally, the dispersion on the electric lighting illuminance results exhibits a reasonable accuracy within 10-15%, indicating that electrical consumption calculations based only on electric lighting are more reliable than the ones relying on a combination daylight and electric light.