Progressive evaluation of daylight ambiance in architectural projects with Radiance

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Abstract: Radiance, as a mature and validated light distribution calculation system, offers a number of possibilities to technical specialists and artists, for natural and artificial lighting simulations. Since, in its basic form, it is command-line oriented and not easy to master, most novice users don't recognize its strength and give it up easily. More experienced users, in everyday work, use numerous software tools to enable: input data preparation, execution of Radiance calculations and results analysis. In our projects we use various software, developed in De Luminae or by other Radiance users, to calculate buildings' static and dynamic daylighting performances.

Architectural project is not a fact, it is a process, where level of future building's details is increased in each phase of the project: from sketch, through rough project design and detailed project phase, to building construction and usage. In this paper, we'll present progressive daylight ambient evaluations of an architectural project and the methods and Radiance based tools we use. We'll also describe some methods used for buildings evaluation in accordance with Certivéa recommendations, for High Environmental Quality buildings.

Keywords: Radiance, daylighting, performance, Certivéa, HEQ, Architectural Design

Introduction

Radiance software is an invaluable tool for accurate physically based lighting calculations. Validated backward-raytracing algorithm and set of basic Radiance tools provide excellent basis for implementation of additional methods and algorithms in lighting calculations, such as dynamic daylight calculations, energy consumption calculations, lighting comfort and glare calculations etc.

Since classic Radiance is organized as a set of separate command-line programs it is not easy to master, and most novice users don't recognize its strength and give it up easily. Being able to calculate light distribution with Radiance and get valid and accurate results, either in visual or numerical format, requires years of work and big support from Radiance community.

Experienced users, in everyday work, use additional software tools to make Radiance calculations easier. Most of these tools are scripts written in bash or csh shell, Python, Perl or other script languages. Although they make job execution more automatic and are flexible and generally portable, include changes and enabling visualization of results can be very tedious. However, scripting techniques needed for any serious Radiance calculations, are far beyond typical (inexperienced) user knowledge.

Another approach is to use GUI-based software, like Daysim, Ecotect, IES module VE, falsecolor2, which enable less proficient users to do complex and accurate Radiance based calculations, without detail knowledge of all Radiance mechanisms and algorithms. These tools are less flexible than scripts, since their functionalities are strictly determined by GUI definition. Note that most of these tools provide extension of classic Radiance calculations in the form of additional analysis of Radiance numerical or visual results, lighting calculations for some time period, graphic presentation and analysis of results, connection of lighting results with energy consumption calculations etc.

To calculate buildings' static and dynamic daylight performances, we use various Radiance-based software tools. We tend to develop GUI based tools, for various phases of Radiance analysis: input data preparation, execution of Radiance calculations and results analysis. All our tools are written in Python and C, and hence are portable to various operating systems. For GUI definition we use wxPython [wxPython] which is supported on various computer platforms, so GUI is independent of operating system. We distribute our software under GPL open source license on our site www.deluminaelab.com.

De Luminae focuses its activities on consultancy and research of natural and artificial lighting, its impact on energy savings and the comfort of interior and urban ambiances. We propose to architecture professionals and their clients a choice of activities for the improvement of natural and artificial light for luminous ambiances and their impact on summer thermal ambiance within sustainable development.

To investigate the impact of light within architectural and urban projects, we perform analysis using various software tools, in particular Radiance and tools developed from it. In past few years, we've been working on various research and commercial projects in France, in the field of daylighting and sustainable architecture. We also have experience on buildings certification procedures related to HQE labels.

Architectural design is a process, though not linear, where level of future building details is gradually increased: from idea and first sketch, through rough project design and detailed project phase, to building construction, usage and maintenance. As project evolves, definition and calculation of various daylighting performances of the future building become possible. In sketch phases, only basic daylight availability on the site and building envelope can be estimated. Later, when geometry and materials are specified more precisely, more daylight calculations are possible, like (il)luminance distribution on surfaces, daylight factors, glare, daylight autonomy, electric energy demands and other static and dynamic performances. Radiance calculations can follow architectural projects in each phase, and give adequate results. If additional software tools are used to simplify calculation and analysis, accurate results can be achieved much easier and faster. Analysis and presentation of results is an important step in better communication between lighting specialists and clients, and shouldn't be overlooked as a part of daylighting analysis process.

In this paper, we present progressive daylight ambient evaluations of an architectural project and methods and Radiance based tools we use. We'll also describe some methods used for buildings sustainability certification in accordance with Certivéa recommendations, for High Environmental Quality buildings.

In the next sections we'll present Radiance based tools and methods via a case study of a real architectural project. For each phase of the project evolution, daylight performances are listed, and methods we use for their calculation are described. For the test case study, we'll show some visual and numerical results, and also recommendations for further project development. This process leads us to the final project phase, where the good daylight performances are achieved, without big changes in architects' original ideas.

Certivéa labels

Similar to **LEED** green building certification system in the US [USGBC], in France, national institute Certivéa [Certivéa] defines building performances which should be achieved in order to achieve **High Environmental Quality (HEQ)**[1] labels for new or renovated buildings.

HQE [HQE] is a French national certification label for residential and non-residential buildings. It covers various types of buildings like hotels, schools, residential buildings, offices, health centers. The system identifies 14 environmental issues and covers two aspects: environmental quality of the building, and environmental management of the entire project. 14 targets fall into four main areas:

- <u>Site and Eco-construction</u>: relation between the building and its immediate surroundings; integrated choice of products and construction materials; low-impact construction site
- <u>Eco-management</u>: energy, water and activity waste management, maintenance-environmental performance conservation
- <u>Comfort</u>: hygrothermal comfort, acoustic comfort, **lighting,** odors
- <u>Health:</u> sanitary quality of spaces, indoor air quality, sanitary water quality

Three levels of performance are defined: **basic**, **good**, and **very good**.

"Basic" level corresponds to current regulations or normal practice. Certification will be granted upon achievement of a minimum environmental profile, comprising a "very good" rating for at least three issues, "good" for at least four and "basic" for no more than seven.

HEQ requirements for daylighting use, in particular, daylight factor as a measurement of light quantity and contrast for comfort but without threshold. For each interior space, a zone is identified covering a surface from the facades to a given limit distance in the interior space. Inside that zone, daylight factors must reach defined levels as in Table 1. Table 1 is just an extract of the requirements, more details can be found in [Certivéa].

Label name	**Conditions**
Basic	**DF >= 1.5%** in 80% inside the zone for 80% of all spaces
Good	**DF >= 2%** in 80% inside the zone for 80% of all spaces **DF >= 1.5%** in 80% of the remaining 20% of the spaces
Very good	**DF >= 2.5%** in 80% inside the zone for 80% of all spaces **DF >= 1.5%** in 80% of the remaining 20% of the spaces **DF >= 0.7%** in 90% of the spaces

Table 1: HQE labels for daylighting [Certivéa].

Comparison of various building certification systems can be found in [UNIP].

Progressive evaluation of daylight ambiance in architectural projects

As mentioned in Introduction, architectural design is a process, where the level of available data progressively increases. In various phases of the project development, appropriate performances of daylight ambiance can be calculated, in order to give estimation of current quantitative and qualitative characteristics of the ambiance, and also suggest possible improvements in the daylight concept chosen for the building to support the architectural intentions.

1 Original French name: **Haute Qualité Environnementale (HQE)**

Below we'll present performances that can be calculated during the project evolution, and some of the results for an example project.

Project case study

Project consists of a tower building on the west and four smaller buildings surrounded by water areas – Figure 1. Tower has 27 floors and is composed of west and east building, connected with bridge construction. West, south and east facades are enveloped with metal mesh and additional sun protections. All calculations presented in further sections are performed for the 19^{th} floor of **tower building.** Floor level distance from the ground is 72m.

Figure 1: VP building area (north is towards top of the site). New buildings are tower and four smaller buildings on the right - east from tower.

Objectives of the study

The purpose of that study was to determine the efficiency of the mesh and protections surrounding the building, but also its impact on daylighting on interior spaces.

- Assess the efficiency of the protections: make sure that protections decrease the impact of direct sun in an efficient manner.
- Ensure that there is still enough daylight in the interior spaces

List of calculations performed

Building 3D model is defined in SketchUp and then exported to Radiance with su2rad plug-in [su2rad]. For calculations and simulations we use various software tools, all based on Radiance algorithm.

In the Table 2 are listed values calculated and tools we used. Also level of defined project details is specified, to give an idea about current phase of the project.

Level of project details	Calculated value	Software
Site description + building basic geometry and position	Shadow paths	RadSunpath
Facade geometry with few sun protection alternatives defined	Exposure to direct sun	SunExposure
Basic inside geometry + basic materials (gray reflectance values) + few sun protection alternatives with materials defined	Daylight factor and HEQ labels	Radiance (dayfact script) + RadDisplay (false color images, comparison of alternatives, HEQ calculations)
Materials details are specified + typical view points (work planes positions)	Visual comfort + contrasts	Radiance + RadDisplay
Occupation profiles and user behavior	Annual calculations (illuminance profile, daylight autonomy, etc)	Paclight

Table 2: Description of architectural project details defined in each phase and list of possible calculations and tools used for them.

Architectural project: sketch phase

Decisions made in early project phases regarding daylighting strategy, have great influence on final daylight ambiance. That is why estimation of lighting quality and quantity in this phase of the project is very important [Mudri96]. Calculations performed in later project phases, although potentially more accurate, can only be used to describe building ambiance, since alteration of building geometry and materials is far harder and more expensive than in earlier phases.

In early, sketch phase of a building design, only site characteristics (geometry, climate and landscape) and global building geometry are defined, in general without facade and inside area details. In this phase there are a number of things that can be adapted in the building design to achieve good building performances regarding daylighting. One of the first tasks of daylight analysis is to calculate impact of the future building on natural lighting of surrounding areas, and also availability of direct sun on the facades.

Shadow paths

Since in the example project, main building is designed as a tower, its impact on shadowing of surrounding area can be significant. Most of already existing buildings are at rather big distance, except buildings in group south of 4 smaller buildings. In this building complex, four smaller buildings east of tower, will be in shadow during the afternoon hours. We explored the impact of the tower on shadows with RadSunpath program. On Figure 2 shadows are represented for 2 time moments during summer solstice.

RadSunpath [RadSunpath] has been developed by De Luminae to enable easier sun and shadows path calculation and visualization with Radiance[2]. Graphical user interface is simple and intuitive, so no professional Radiance skills are required for program usage. Program creates a set of Radiance images for a project, for selected date and time step, and includes them into final gif animation file which represents the sun and shadows path during the selected date.

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2 Various tools exist for shadow paths visualization. Some of them are included in other software like SketchUp.

We also developed a SketchUp plug-in for import into RadSunpath, with help of Thomas Bleicher. Idea is to import project details, exported to Radiance by su2rad, directly into RadSunpath and enable user to calculate sun and shadow paths even without detailed knowledge of Radiance syntax. RadSunpath and SketchUp plug-in are under GPL license.

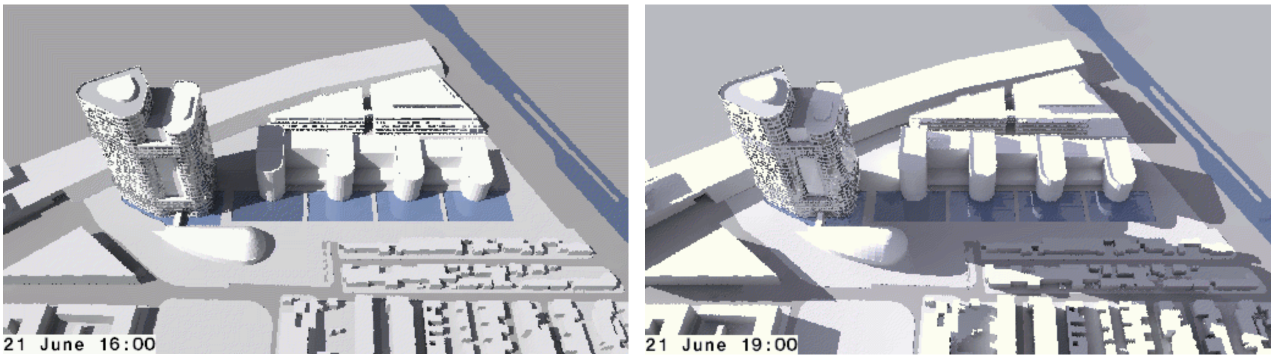


Figure 2: Shadows from tower: 21st June, 4PM (left) and 7PM (right)

Exposure to the sun

In the sketch phase of the design, the quantity of light available on the facades can be calculated. Light available can be calculated as total or average irradiance or illuminance coming on the facades for some time period. For these calculations Francesco Anselmo's radmap tool [radmap] can be used.

For this case study we calculated another interesting measure of daylight availability - **sun exposure**. It can be described as a number of hours during some time period, when direct sunlight strikes building facades, opaque or glazed. According to WMO [WMO], direct sun is visible on the sky if direct normal irradiance of the sky is above 120W/m2. Sun exposure for facades can be calculated during early phases of a building design, and influence important decisions related to building lighting and thermal strategies [Cvet06]:

- Selection of facade materials – in accordance with their light sensibility.
- Suggest position of windows on the facades
- Suggest which parts of the building need special sun protection, to avoid glare
- Evaluate the efficiency of proposed sun protections, visualize potential risks of overheat
- Suggest best places for photovoltaic cells
- Suggest areas of the building which can be used for passive solar heating -"greenhouse effect"
- Suggest areas on the facade that should be insulated to prevent overheating or overcooling of the building.

Sun exposure of a point on the facade depends on building site and its weather, and also of building shape and facades orientation and sun protection. It is independent of materials used on facades or environment and also of building interior. For calculation of exposure to the direct sun we use SunExposure program.

SunExposure is Radiance based program which calculates sun exposure of sensors on building facades. It is designed to enable fast lighting calculations in earliest phases of the building design. For specified building and environment geometry, weather data file and facade surfaces (polygons in Radiance format), program generates sensor points on the facades and calculates if sensors are exposed to direct sunlight or not, for each hour during one year period. Program also calculates incident angle of the direct sunlight onto facade surfaces. These results are used as a criteria for estimation of sun penetration depth into the building interior (deep, middle or close to façade). Output format and visualization of incident angles and penetration depth results are still under development.

On output program provides textual file with results summary for each season and year period, and also images with results presented in false colors. False color scale is specified in GUI, and results can be presented as points or as false color surfaces. GUI is understandable and results are very useful for early phases of architectural projects.

SunExposure is officially not released, since program GUI is still under construction.

Example building is an interesting project for sun exposure calculations, because architects proposed building envelope made of metal mesh, with additional vertical translucent light protections for sun protection and exterior horizontal curved specular shelves for light redirection into the building interior – Figure 3. These sun protections and mesh are designed in front of east, west and south facades.

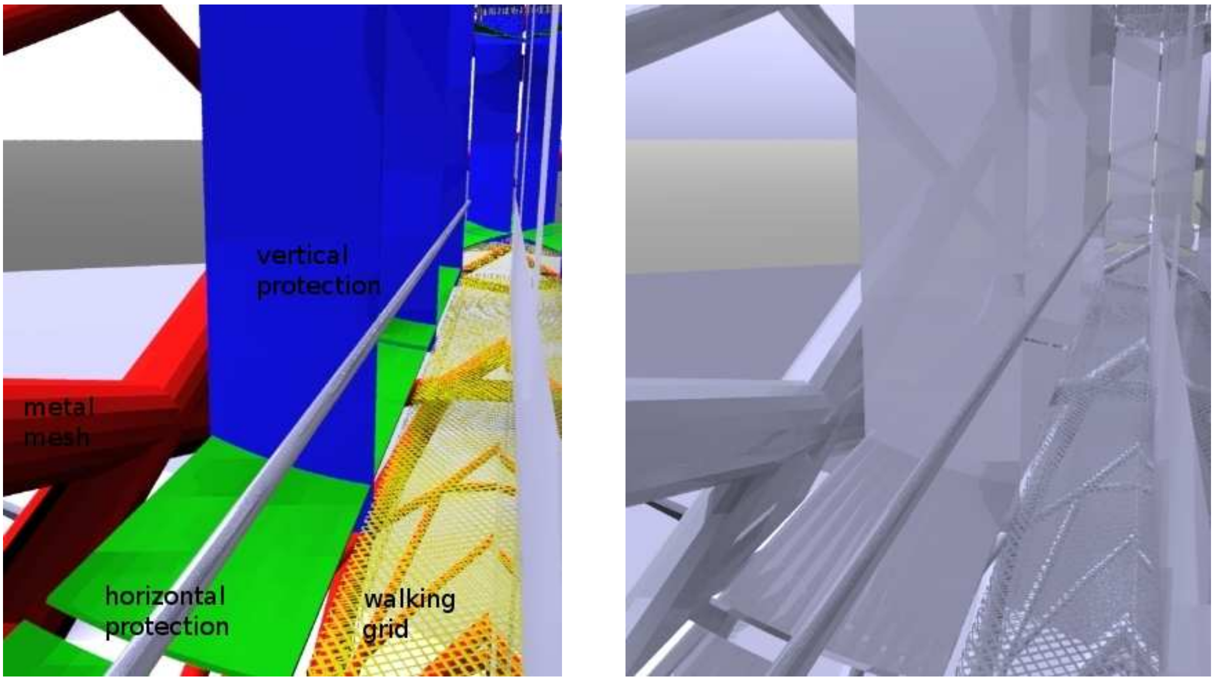


Figure 3: Sun protections on west, south and east façade. Left image false color dummy materials and description; right image – materials used in calculations.

We calculated exposure to the direct sun with SunExposure tool for building with and without sun protections and mesh. All values are calculated for appropriate Paris weather file, from EPW database [EPW], so results can be considered as typical for this site. Results are presented on Figures 4 and 5.

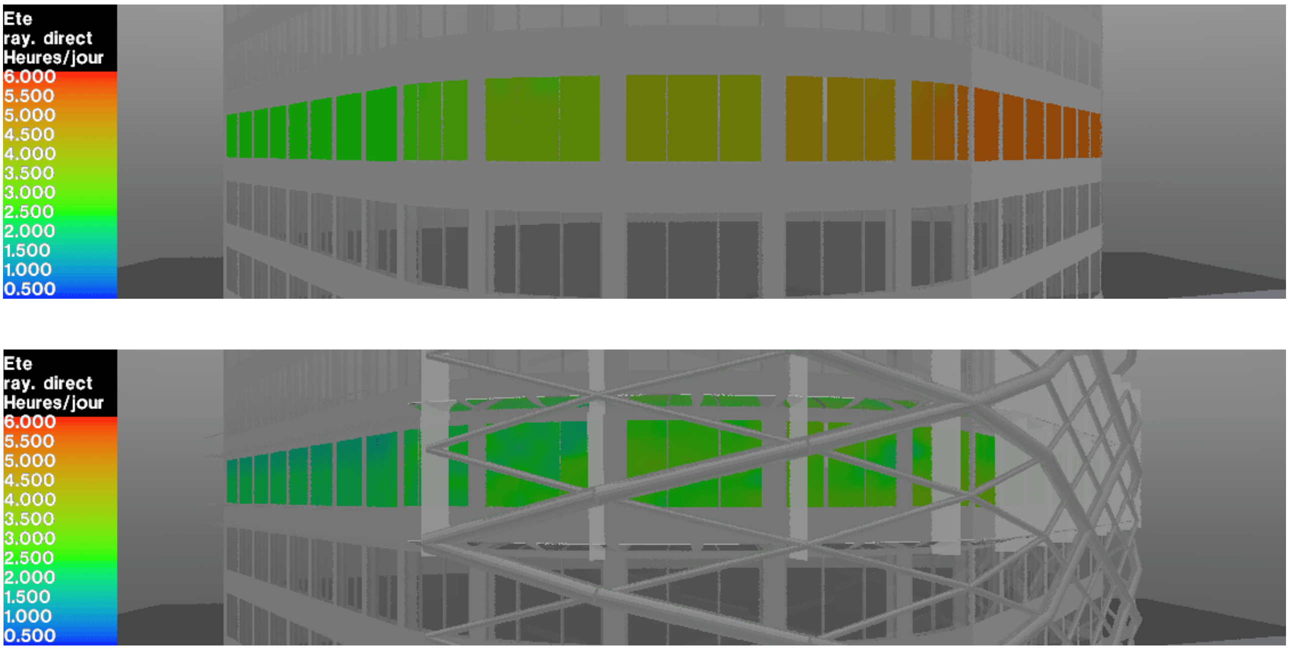


Figure 4: Average daily sun exposure for summer period without (top) and with (down) sun protections, for west part of the building. Facade on the left side of the building is oriented towards north, central curved part is west side, and right part is south facade of the building.

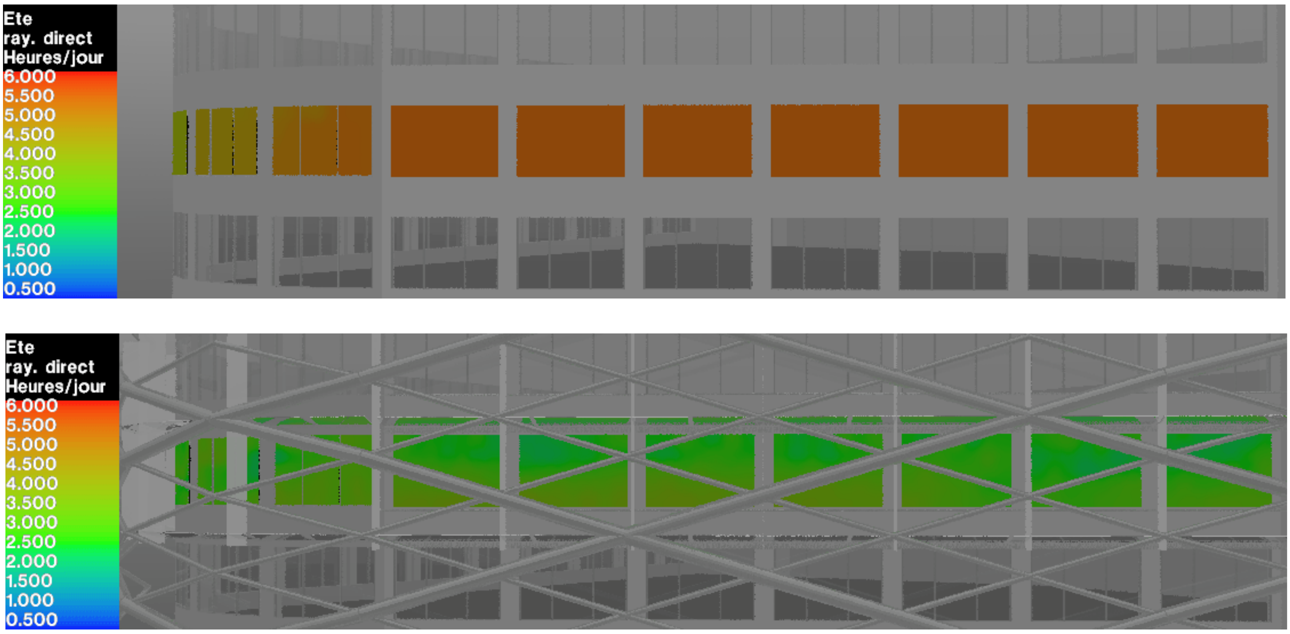


Figure 5: Average daily sun exposure for summer period without (top) and with (down) sun protections, for south facade.

On the above images, one can see that sun protections and metal mesh decrease the number of hours during the day when direct sunlight is coming on the building facades. On the north facade neither mesh, no protections are defined since direct sunlight is coming on average 2h per day during the summer, and even less during other seasons. Impact of sun protections is most visible on the south façade, where sun protections decrease sun exposure by approximately 2-3h/day. When without protections, south facades get direct sunlight approximately 5.34 h/day during summer period, while with sun protections values are between 2.5 and 3.5h/day.

Positive aspect of this result is that potential for glare occurrence and overheat inside the building is reduced because of the protections used and the thermal analysis confirmed that this choice of protection and mesh is compatible with norms. This common work with the thermal analyst allowed defining a protection that respects both points of view. On the other side, these protections may decrease light levels inside the building below acceptable levels, create discomfort due to contrasts of the mesh on the sky and also produce various shadow shapes inside the building which may make work inside uncomfortable. Impact of protections is explored deeper in next phases of the analysis. Still some mobile blinds need to be defined to eliminate the remaining direct sun.

Architectural project: basic preliminary design

After these first calculations of daylight availability on building facades, later in the design process more details about building outside and inside geometry become available: position and size of windows, basic materials' characteristics and some performances of daylighting can be evaluated. At this stage materials may not be completely defined, but their reflectance may be known even approximately. So we can define materials with their gray reflectance values (or use the actual characteristics if defined). If unknown we generally define glazing as double clear glazing with transmittance of 70%. These details enable first calculations of building interior daylight ambiance, hence daylight factor calculations on work plane can be performed, and also comparison to HEQ labels requirements.

Daylight factor and HEQ labels

For selected basic materials and inside geometry, we calculate daylight factors for work planes in example office on south side of the building. To calculate DF values, we adapted Radiance dayfact script and calculated illuminance images. Then with RadDisplay, calculated images are previewed as false color images for estimation of fulfillment of HEQ requirements.

RadDisplay [RadDisplay] has been developed by De Luminae to answer two basic needs: Radiance image viewing and image analysis with pixel tracing and false color methods. Since Radiance image format is specific and carries out more data than classical image formats, information saved within the image cannot be easily studied without the use of Radiance programs. In that respect, we could only provide our clients images in "more classical" format and a textual analysis of them. In order to give clients the freedom to further investigate themselves the images resulting from image simulations, we developed a Radiance image viewer that does not require Radiance knowledge and previous Radiance installation. For detailed analysis of image pixel values, false coloring is in our view a very powerful tool to investigate images. It is also a great communication tool for technical images such as Radiance images. RadDisplay has advanced interface for false color scales definition, user can set number of colors, precise colors limits, chose colors for the palette etc.

RadDisplay is available under GPL license on our website.

In the project under study, architects proposed construction of metal walking area around the building on each floor below windows, for windows washing and maintenance of metal mesh and sun protections. Impact of three options on internal illuminances was analyzed: no walking area at all or a moveable one, walking area made of metal grid (with small holes), and walking area made of opaque reflective metal – like light shelf above the windows. For all three cases, metal mesh around the building and horizontal and vertical protections are included in the building geometry.

On Figure 6 are given illuminance and false color images of the work plane for south facing office, for these 3 alternatives. On false color images palettes are adapted to daylight factor requirements for HEQ labels calculation. Black lines parallel to the facade, are positioned on the internal facade level and on appropriate distance from the facade to define zones for HEQ calculations.

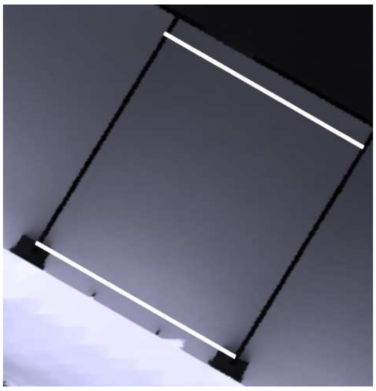
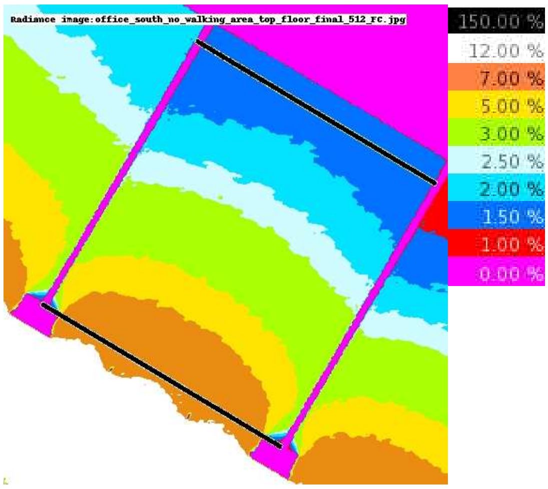
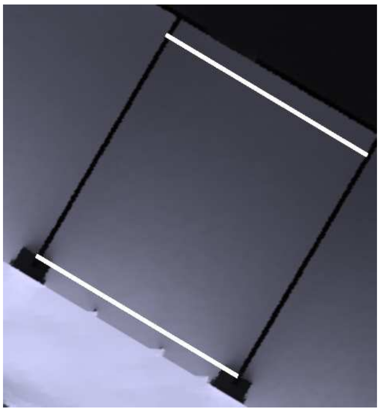
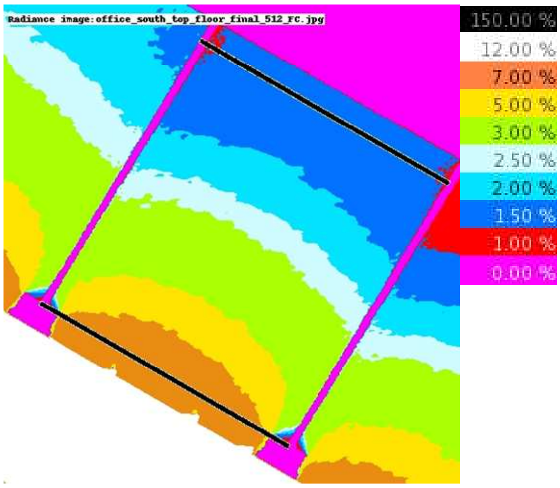
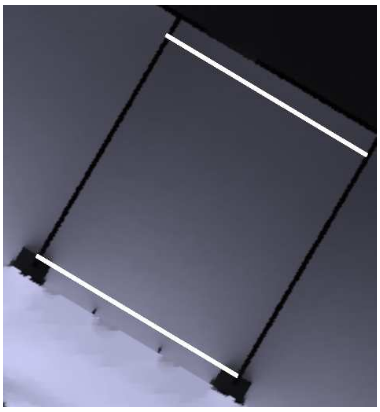
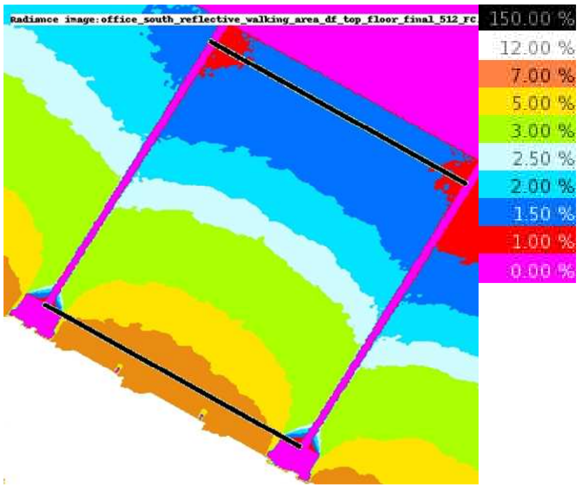
<table>
<tr><th>Illuminance image of work plane</th><th>False color DF image of work plane
(palette is adapted for HEQ labels calculations)</th></tr>
<tr><td>No walking area
</td><td>
</td></tr>
<tr><td>Grid walking area
</td><td>
</td></tr>
<tr><td>Reflective walking area
</td><td>
</td></tr>
</table>

Figure 6 Illuminance images and DF false color images for HEQ labels calculation. Tree walking area options are analyzed.

Table 3 - Percent of zone area with DF values above HEQ threshold values.

Protection	> 1 %	> 1,5 %	> 2 %	> 2,5 %
No walking area	100 %	100 %	84 %	67 %
Grid walking area	100 %	100 %	76 %	60 %
Reflective walking area	100 %	100 %	74 %	59 %

In Table3 is given the percent of zones area above certain DF threshold values, in order to estimate HEQ requirements fulfillment.

From FC images it is obvious that the amount of light near the window is the highest for test case without walking area round the building, while both cases with walking area, grid and reflective one, give similar DF values. For the entire work plane, based on the Table 3, case without walking area has higher percent of the area above all threshold values, than other two cases.

Related to HEQ requirements, case without walking area achieves “good” daylight performance, since 84% of the zone has DF values above 2%. For other two cases “basic” daylight performance is achieved.

Architectural project: detailed preliminary design

Since DF is calculated for CIE overcast sky, no direct sunlight is taken into consideration for these images. As a next step we should make calculations with realistic clear sky, and see if various walking area materials make significant differences in light ambiance and glare inside the offices.

Luminance and contrast analysis

To achieve comfortable daylight ambiance in some space various quantitative and qualitative performances should be achieved. Visual comfort requires that luminance of surfaces within field of vision is acceptable, and that contrasts are within acceptable ranges, to avoid glare occurrence.

We created luminance images for view point above the work plane, a likely point of view for an office user. View is oriented towards window and two walking area materials are studied: metal grid material and opaque reflective metal walking area. Images and FC representations are given in Figures 7 and 8 for two walking area alternatives. Both images are for office with windows oriented towards south.

General distribution of the surfaces luminance in the room is similar for both tested cases, except for right wall. On this wall shadow patterns from the grid walking area are clearly visible, while reflective walking area doesn't make such patterns. Although for simulated sun position and viewer location grid shadow patterns don't have effect on work plane luminance, it should be noted that for afternoon hours or for different position of the viewer, these patterns can make unpleasant shadows on the work plane and make work uncomfortable or even impossible, but in any case that will be the architect's choice to balance the consequences of one material or another.

Luminance contrast for work plane and surrounding surfaces and glazing are within acceptable range so this ambiance can be considered as comfortable for work, even for the window wall that was chosen white (we work on contrasts according to AFE recommendations [AFE] and [Energy92]). Also metal mesh envelope and sun protections don't obstruct direct line of view for the user, while they make view to the outside interesting, without too big contrasts.

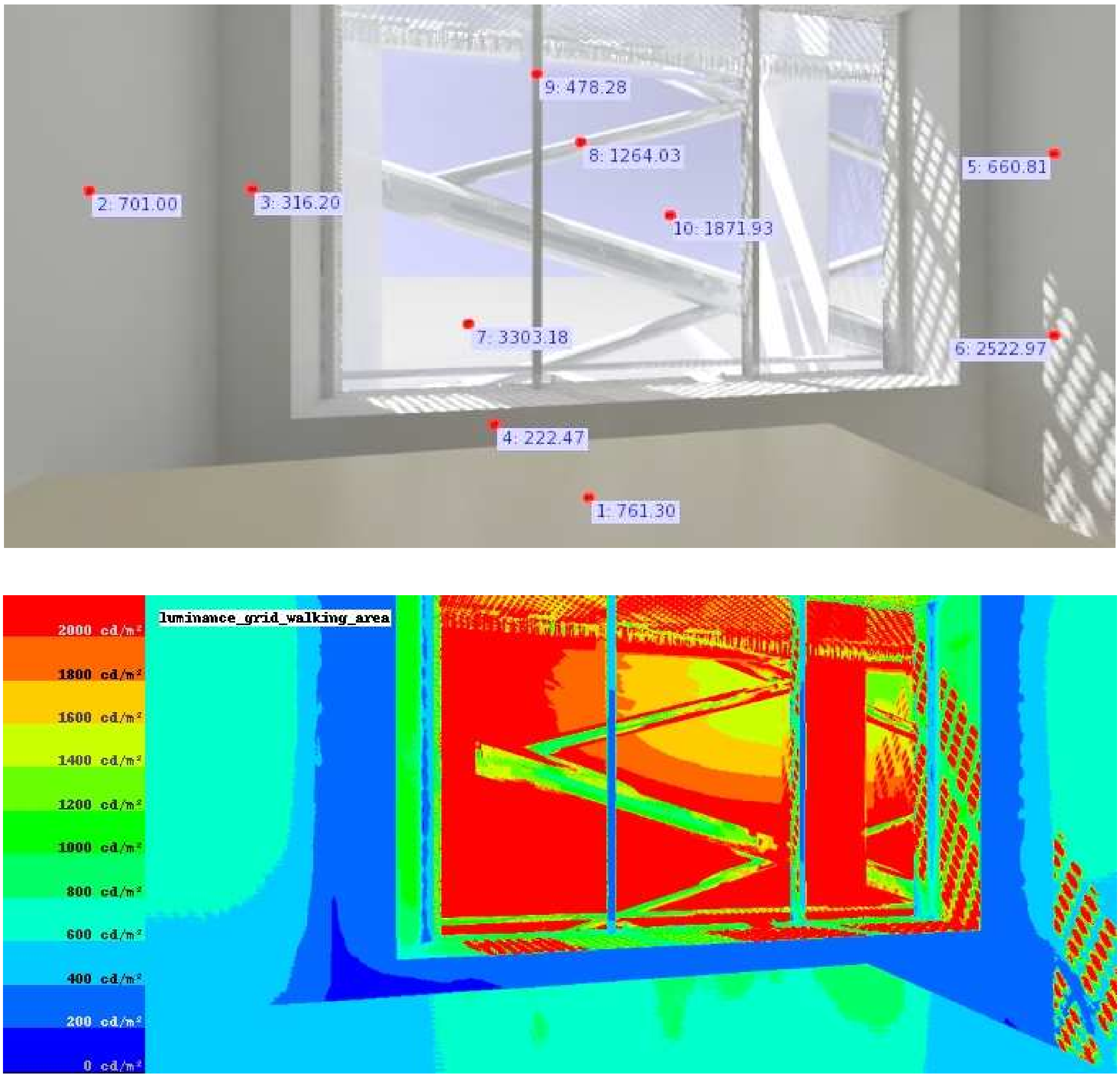
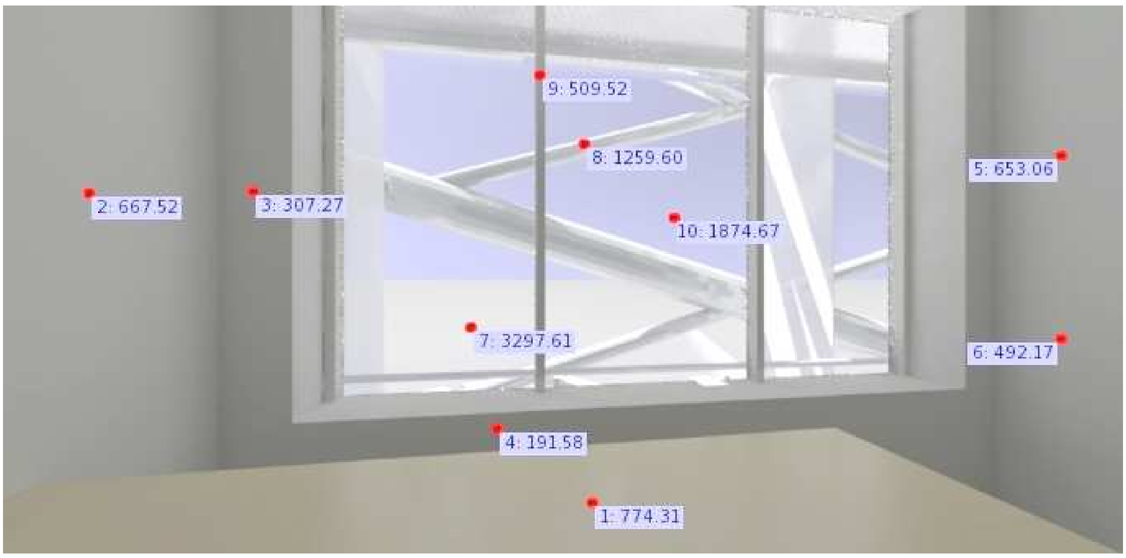


Figure 7: Images for metal grid walking area. Top: Radiance image, with luminance values for office surfaces. Bottom: False color representation of radiance image.



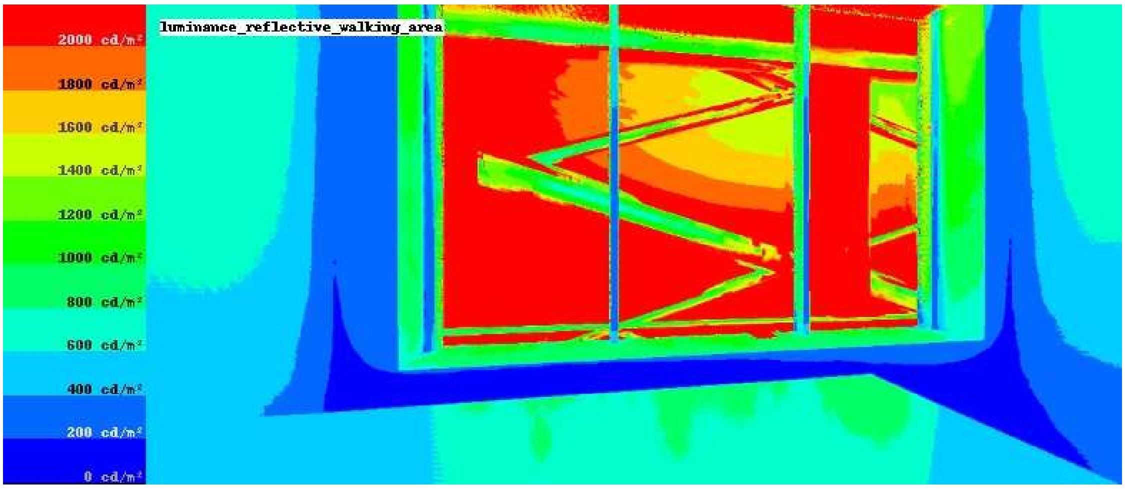


Figure 8: Images for reflective metal walking area. Top: Radiance image, with luminance values for office surfaces. Bottom: False color representation of radiance image.

Dynamic daylight calculations

Daylight performances like DF or (il)luminance distribution are related to one specific sky luminance distribution and don't give general view on daylighting ambiance of future building. Sun exposure and shadow patterns give dynamic view to outside daylighting conditions, while other building performances should be calculated to obtain information about real building performance over time, for specified building site and weather conditions. These dynamic performances like Daylight Autonomy (DA), Useful Daylight Illuminances (UDI) and others [Reinhart06] can be calculated with Radiance with few additional tools and methods. For dynamic calculation Daysim [Daysim] can be used or classic Radiance with rtcontrib and 3-phase approach [Ward09].

De Luminae participated in a French project **PACIBA**. Project goal was to develop a set of software tools that can calculate various aspects of building energy demands and comfort. De Luminae developed daylight calculation module – Paclight**.** After project finalization, Paclight module has been included in Alcyone software.

Paclight [PACIBA10] takes on input building geometry and materials (in Radiance format), climate file (in epw, try, wea or Satel-light format) and reference planes definition, and gives on output annual illuminance profile for specified reference planes.

For specified reference planes and preferable number of sensor points, Paclight generates rectangular grid or Delaunay triangular mesh of sensor points. Annual illuminance profile is calculated with an algorithm similar to Daysim, whereas daylight coefficients are calculated with rtcontrib. Sky luminance distribution model used in Paclight is Perez sky model, while DCs number and position is in accordance with Daysim sky discretization scheme.

Accuracy of Paclight in comparison to Daysim and classic Radiance brute force approach has been tested during PACIBA project. Paclight and Daysim give illuminance results of similar accuracy, with average error 6 - 9% in comparison to Radiance brute force calculation. If compared to constant illuminance threshold, for daylight autonomy or UDI calculation, both Daysim and Paclight give similar results, where differences to classic Radiance results are from 1.67% for 1000lux threshold to 7.69% for 300lux threshold. For each tested algorithms, classic Radiance, Daysim and Paclight, optimal set of parameters is used – determined during detailed research and comparison on test cases during Paciba project [PACIBA10].

Paclight calculation can be executed in parallel threads, which enable shorter calculations. With the increase of the number of parallel threads, calculation time is decreased almost linearly in Linux, while in Windows accelerations are lower but still significant. Detailed analysis of calculation times and comparison to various Radiance and Daysim based approaches can be found in [PACIBA10].

Calculation of annual illuminance profile and daylight autonomy can give us interesting information about daylighting ambiance and also enable comparison of various project alternatives. We investigated influence of a building interior materials on internal illuminance, daylight autonomy (DA) and potential energy savings. In paper [Velick09] we presented results of dynamic daylight calculations on Qualis building, and comparison of electric light requirements for floor materials with reflection in range from 3% to 20%. Qualis project was a reconstruction of a tower building, with open space offices. Although differences in DA near the facades were negligible, for areas deep in the building, potential energy savings were up to 20% if lighter floor material is used.

These results give useful information to architects regarding choice of materials for the building, in order to achieve good daylight ambiance and comfort. Also, results like these indirectly suggest good artificial lighting design for the building, where complete floor area can be divided in few zones controlled with separate electric circuits and switches.

For this tower project we calculated DA for two floor materials with reflectance 30% and 10%. Other project parameters were equal for both alternatives, with ceiling material with 80% reflectance and walls with 70% reflectance.

DA for offices oriented towards south and north, has shown that DA in small spaces, positioned near the facades is not influenced significantly by surface materials, since biggest amount of work plane illuminance comes directly through the windows.

Zone	**DA [%] (floor 10%)**	**DA [%] (floor 30%)**	**ΔDA [%]**
1	23.79%	33.18%	39.47%
2	80.11%	80.91%	1.00%
3	69.41%	72.34%	4.22%
4	81.31%	82.68%	1.68%
5	1.50%	4.93%	228.67%
6	3.21%	16.64%	418.38%
7	34.01%	43.93%	29.17%
8	40.65%	52.41%	28.93%

Table 4: Daylight autonomy[%] for work plane zones for 19th floor of east tower. Values are calculated for period between 8AM and 6PM, for illuminance threshold value of 500lux.

Second column: average DA for case with floor with 30% reflectance, while third gives values for 10% reflectance floor. Last column: relative difference between DA values=(DAfloor30 – DA floor10)/ DAfloor10

Figure 9: Position of sensor points and division of work plane into zones.

Similar calculation was performed for east building tower, since it is planned to be open space. We've done calculations in 28 points, for 2 floor material alternatives, and based on DA results we grouped all points in several zones as presented on Figure 9 and Table 4. DA values are calculated for working hours between 8AM and 18PM, for illuminance threshold value of 500lux.

Zones near the facades 2, 3, 4 have the biggest DA and it is not significantly influenced by floor material. Zone 2 is oriented towards south and east and it gets more light than zone 3 which is oriented towards east. Zone 4 is oriented towards north, but since no sun protection equipment is designed on this part of the facade it also gives DA values above 80%.

Zones deeper in the building 1, 7 and 8 have potential energy savings of 30-40% because the greatest part of the light that reaches these zones is reflected from floor and other internal surfaces.

Zones 5 and 6 are planned to be connection between 2 building towers. They are far from all facades, so even brighter floor material can't produce high DA values. Differences in DA are huge for these zones because most of the light is reflected from internal building surfaces.

Based on results analysis floor material has a major influence on internal illuminances, and should be taken into consideration when daylight ambiance is analyzed. As expected influence near the facades is not significant, but deeper it the building is can be rather big. Beside recommendation to use brighter floor material, results like this suggest good organization or electric lighting installation. It also helps a lot to enhance the awareness of architects and promoters regarding the importance of materials. Saving energy is not necessarily costly! Luminaires and switches should be organized in zones: one zone for areas near windows where light will be turned on only in late afternoon hours; one zone for deeper areas - where light will be turned on approx 50-60% of the occupied time, and third for zones 5 and 6. Note that internal zones are supposed to be used as corridors with light requirements lower than 500lux, so actual DA in zones 5 and 6 should be calculated with illuminance threshold 300lux or even lower. For illuminance values of 300lux and floor with 10% reflectance, zones 5 and 6 have DA values 19.2% and 30.41%.

Conclusion

In sections above we presented evolution of an architectural project on an example. Daylight ambiance analysis is a process which evolves with the project. We have shown which daylight performances can be calculated in various phases of a project design, and how they can influence on architects decisions related to building's (day)lighting strategy.

Through this analysis we presented few Radiance based tools we developed and use in our practice to make calculations and analysis easier, and present results more understandable to non-technical clients. All our tools are GUI based, written in Python and C and hence portable to various operating systems. They are also released under open source license and available for free on our site www.deluminaelab.com.

For early project phases we use RadSunpath to calculate and visualize sun and shadows paths during the day for the project site. SunExposure can be used to calculate number of hours when facades are exposed to direct sunlight, for some time period. In more detailed phases of the project, daylight factor can be calculated and compared to HEQ requirements. For calculation we used classic Radiance tools, and visualized and analyzed results with RadDisplay false color options. Dynamic daylight performances of the building like annual illuminace profile and DA can be calculated with Paclight module, which is developed as a part of PACIBA project.

Estimation of daylight ambiance of a building is complex process that follows evolution of a project, and gives more precise data in each step of the building design. If communication between architects and lighting specialists is adequate, it can enable usage of better daylighting strategies, and enable bigger energy savings and more comfortable daylight spaces.

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