A First Application of the Lightsolve Approach:
Pre-design of the new Belgian VELUX headquarters

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ABSTRACT: This study presents the application of the "Lightsolve" method on the pre-design of a new sustainable building in order to optimize its daylighting. At the time of the project, this method combined climate-based illuminance and glare evaluations with visual renderings. Illuminances were presented according to a goal-oriented approach and glare was evaluated through the DGP. Both were displayed on temporal maps. The Lightsolve method was used to size lateral and zenithal openings and shading devices. A first conclusion of the study is that it is necessary to couple daylight metrics with a solar gain metric. Comparison between Lightsolve and daylight methods used in rating systems showed that these ones do not give enough accurate information for optimizing the daylighting design. Designer's satisfaction evaluation showed that the goal-oriented approach and the temporal map representation were appreciated although this latter was rather difficult to understand. It also showed that an expert tool should be proposed in order to help designers to analyse their results. Finally, it was pointed out that the quality of daylight should be evaluated in Lightsolve, which will be done through a PhD work.
Keywords: daylighting, design process, simulation, performance metrics

INTRODUCTION

VELUX*Belgium*, which is part of the VKR group, decided to build a new head office. It was, for the company, the opportunity to build according to their philosophy, trying to decrease the building's environmental impact by choosing a design respectful of environmental, social and economic aspects. Towards this end, VELUX*Belgium* gathered a multidisciplinary team around a common vision to realize a building in a sustainable approach.

The 1500 m^2 built-up area building will be located in Louvain-la-Neuve (Belgium) and oriented along a NorthWest-SouthEast axis. The building, which will rise on three levels, is divided in three parts: a training centre for seminars or workshops, a showroom and offices for employees.

Figure 1 : North-East façade (EVR-Architecten & Atelier229).

The main design objective is to provide the VELUX employees with a high indoor comfort through an extensive use of daylight and natural ventilation. For that reason, our university research team was in charge of optimizing the daylighting design of the building, using a new approach to support architectural design, named "Lightsolve" [1]. The objective was to go through a first application of this method and to evaluate its relevance, main strengths and weak points.

LIGHTSOLVE: AN INTERACTIVE GOAL ORIENTED DAYLIGHT DESIGN APPROACH

Lightsolve, a work in progress, aims at supporting the - inherently non-linear - design process more effectively by combining a goal-oriented approach (suggesting design improvements based on analysis results) and a very visual and interactive representation of annual performance data, both quantitatively and qualitatively [1]. One of its main innovations will be to create an interactive optimization process that will replicate as closely as possible the interaction a designer would have with a consultant [2]. At the time of the VELUX design, this method was still under development, and advice from real daylighting experts was used instead.

As a first application of the Lightsolve approach, we used the pre-design project submitted for the architectural competition of the VELUX HQ building. This project was first analyzed using the metrics and visualization methods explained in the following paragraphs. Then, according to the modification possibilities given by the architects, the experts compared the results to each other and pointed out what the most interesting modifications were.

Time segmentation principle The Lightsolve method estimates the daylighting performance of a space on a yearly basis and uses a time-segmentation method described in [3], instead of producing massive amounts of data. This methodology results in the splitting of the year into 56 time periods and in a weighted average illuminance, representative of the dominant weather conditions for each period (based on TMY2 weather data files). The sky models used are the four types defined by Perez for the ASRC-CIE model [4]. The representative illuminance values are plotted on "temporal map" graphs: x-axis for date, y-axis for time of day, allowing an entire annual dataset to be viewed as one reasonably intuitive graph [5]. But instead of plotting absolute illuminance values, a goal-oriented approach is chosen (see below), and the displayed values are percent values of achieving a certain goal (like falling inside an illuminance range) as shown in Fig. 2.

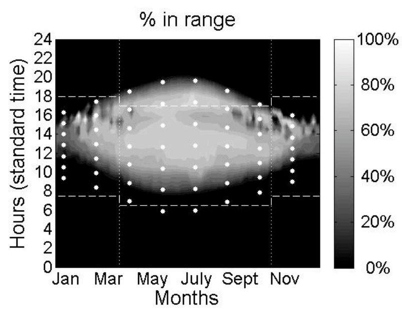


Figure 2: SW-facing office: % of area in range. White dots represent 56 time periods.

RADIANCE was chosen as the calculation engine used to produce the required data, but a faster rendering method, based on radiosity method combined with shadow volumes, is now being implemented in Lightsolve to increase interactivity [6,7].

Goal-oriented approach The principle of the goal-oriented approach is to fix a range of target values and to evaluate the percentage of the space whose performance falls within that range. This approach has the advantage of incorporating spatial and temporal information in the same graph (Fig. 2), which has to be complemented by two graphs specifying why the rest of the space does not fulfil the goals, i.e. whether it was because the values exceeded or were below the target range: one map representing the percent of space having too low illuminance values (Fig. 3) and the other one, the percent of space having too high values (Fig. 4). In the case of the VELUX building, the minimal illuminance value on the office desk was set to 500 lux (with partial credits up to 300 lux) and the maximal illuminance value was set to 1000 lux (with partial credits up to 2000 lux).

Glare analysis The risk of glare is evaluated by the Daylight Glare Probability (DGP) index proposed by Wienold and Christoffersen [8], for one position and one view direction in the room (Fig. 5). In the case of the VELUX building, the DGP temporal map represents either the DGP for the dominant sky type or the maximal DGP (DGPmax), i.e. the DGP for the most glaring sky type occurred at the considered time (Fig. 6).

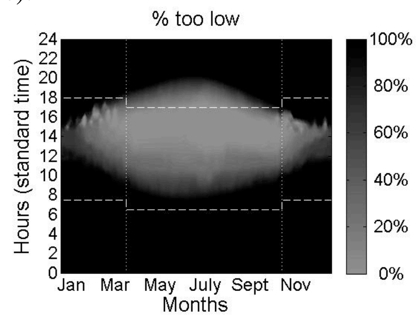


Figure 3: SW-facing office: % of area too low.

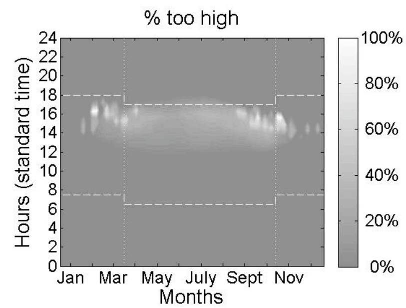


Figure 4: SW-facing office: % of area too high.

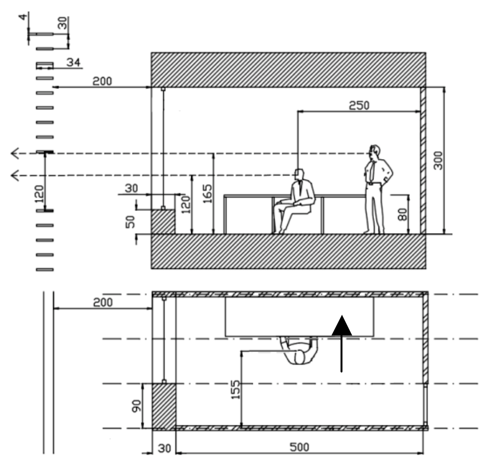


Figure 5: Section and plan of the SW-facing office.

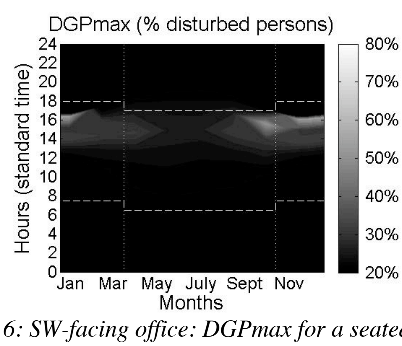


Figure 6: SW-facing office: DGPmax for a seated person.

Visual renderings Simulation results were coupled with visual luminance renderings in the room for each of the 56 periods of the year [1], displayed in false colours (Fig. 7) and organized similarly to temporal maps: days on the x-axis and time on the y-axis.

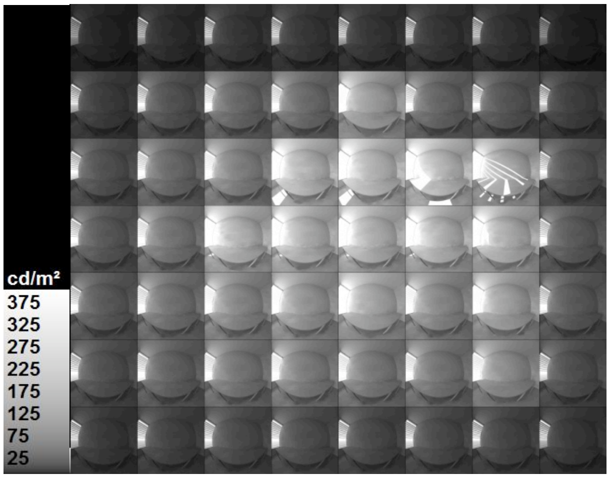


Figure 7: Luminance view in false colours.

A visual rendering of the space for a seated person looking in the direction of the wall is given (Fig. 8).

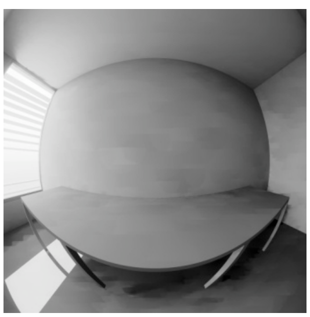


Figure 8: Rendering of the space (May 29, 15:56).

MAIN RECOMMENDATIONS AND IMPLICATIONS FOR THE ARCHITECTURAL PROJECT

Following the architects' demand, the Lightsolve method was applied, at first, to study the window width, height and position, the external louvers position, dimension and slope as well as the wall colours and the influence of an overhang. This study was realized for SW and NE-facing 1-person offices. As a second step, roof windows were studied for offices located on the third floor and for larger spaces as the show-room and the training-centre.

The main modifications resulting from this analysis were to enlarge side windows. Results also showed that zenithal apertures were too large and could introduce glare problems. As dynamic thermal simulations also highlight large overheating risks, these windows were reduced in size. As a consequence of the mainly overcast Belgian climate, the calculated glare probability was rather low in laterally lit rooms when the occupant view direction was perpendicular to the window and focused on the work task. It was shown that, as far as daylighting was concerned, shading devices were not compulsory. Louvers, originally designed by the project architects using a traditional geometrical method, were shown to be over-sized. To take into account pleasantness of the view through the window, for each configuration of shading devices, renderings were compared in parallel with illuminance maps to find the best configuration. This study on shading devices showed that it was possible to achieve similar illuminance levels with different kinds of shading devices. The architectural decision was thus made according to aesthetic aspects on the basis of renderings and luminance views.

This analysis also showed that the desk location and the wall colours were particularly relevant parameters influencing daylight comfort in these offices.

During the study, some questions about the quantity of solar gains entering the building and the risks of overheating appeared. Dynamic thermal simulations were done to answer these questions and revealed the need to define a metric evaluating the solar gains entering the building and to link it to target values, for the considered climate, which are also part of Lightsolve's overall perspectives.

COMPARISON WITH TRADITIONAL METHODS

Before the development of Lightsolve, there was no pre-design daylighting optimization method. However, since the emergence of rating systems, architects tend to use the daylight methods proposed by these systems to optimize their design. The objective of the work presented here was to evaluate the sensibility and tendency of two rating system methods (HQE and LEED) by comparison to Lightsolve. The American LEED and the French HQE rating systems are, respectively, based on the evaluation of an absolute illuminance value at one precise time of the year and on a minimal daylight factor value.

HQE evaluates the daylight in a room by calculating the minimal daylight factor (DF) on a studied area. The depth of the considered studied area is defined by the room and working plane height as shown on Fig. 9.

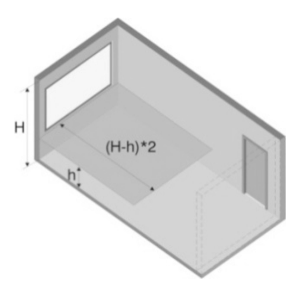


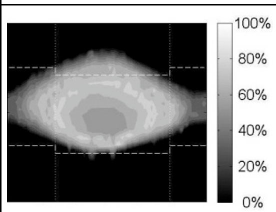
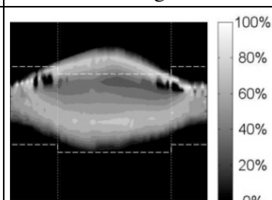
Figure 9: Definition of the study plane in HQE.

According to the DF obtained on the studied area, the room is rated as “good” or “efficient”. If a room rated as “efficient” has a minimal daylight factor on the rest of the working plane superior to 1%, the room obtains a “very efficient” rating. The final building rate is the higher rate obtained in 80% of the rooms.

In the LEED rating system, the studied area corresponds to the whole office area at 30 inches (0,76m) above the floor. LEED suggests achieving a minimum illuminance value of 269 lux in 75% of occupied rooms, for a clear sky on the equinox at noon but no absolute value for the zenith luminance is given. Users are thus allowed to choose this value, which is not trivial to evaluate. For our comparison, the chosen absolute luminance is the value given by RADIANCE, following the LBL algorithm defined in the CIE110-1994 technical report [9].

LEED and HQE give no maximum value for illuminance or daylight factor. Concerning glare, HQE and LEED recommend avoiding high contrasts and controlling glare with common glare control strategies but do not suggest any tool or metric to evaluate the glare risks. In Lightsolve, the work surface is defined by the user and, for the VELUX project, was chosen, over a desk at 0,8m above the floor. Several desk locations in the room were tested. In this comparison, we present the “% in range” temporal map obtained by Lightsolve, completed by the yearly average percentage of the space being in range, too high and too low, as well as the average DGP and average DGP max, if they are between 20% and 80% (values for which the DGP has been validated).

Table 1: Influence of the building orientation.

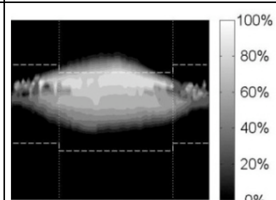
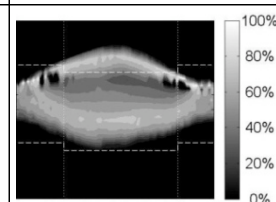
		NE-facing office		SW-facing office
Lightsolve				
	average %	37% in range 7% too high 56% too low DGP = < 20% ; DGPmax = 20.8%	average %	37% in range 19% too high 45% too low DGP = < 20% ; DGPmax = 29.2%.
HQE		GOOD (85% DF > 1.5% and 100% DF > 1%)		GOOD (85% DF > 1.5% and 100% DF > 1%)
LEED		1 credit (100% area > 269 lux)		1 credit (100% area > 269 lux)

The two first models compare the influence of building orientation. Results for Lightsolve, HQE and LEED are reported in Table 1. As the DF (Daylight Factor) is, by definition, calculated under overcast sky, orientation of the building is not taken into account.

Results obtained for HQE are thus the same for the two cases. Evaluation according to LEED certification suggests that illuminance of 269 lux is achieved for 100% of the area, for the two orientations. Lightsolve results inform on the daylight availability through the year and show differences between the two orientations; the NE façade presents mainly too low values of illuminance while the SW façade results show that there is too much daylight at the end of the days, in mid-seasons. Concerning the glare, results suggest that 29.2% of persons, in the SW-facing office, could be disturbed in high luminance sky conditions.

Table 2 shows the comparison of results obtained for SW-facing rooms, with 90 cm-width windows as initially designed by the architects and 180 cm-width windows as proposed by the daylight experts. LEED and HQE analysis would have led to the same conclusions than Lightsolve: the 90-cm windows were too narrow.

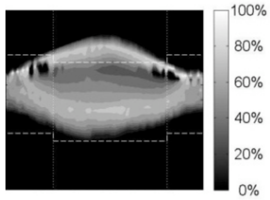
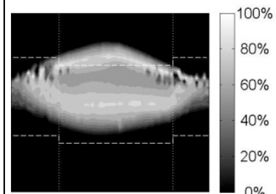
Table 2: SW-facing office: influence of the window width.

		90cm-window		180cm-window
Lightsolve				
	average %	25% in range 3% too high 72% too low DGP = < 20% ; DGPmax = 20.5%.	average %	37% in range 19% too high 45% too low DGP = < 20% ; DGPmax = 29.2%.
HQE		do not respond to the criteria		GOOD (85% DF > 1.5% and 100% DF > 1%)
LEED		do not respond to the criteria		1 credit (100% area > 269 lux)

However while HQE and LEED evaluate the 180cm-window as good, Lightsolve informs about risks of glare. When we obtained these results with Lightsolve, we tried to reduce glare risks and “% too high” illuminance in the SW-oriented rooms by placing an exterior shading device.

The comparison between the 180cm-window SW room and the same room with external fixed shading is presented in Table 3. This shading device reduces glare risks and “% too high” illuminance with almost no reduction of “% in range”. The configuration with shading device is, according to Lightsolve results, better than the other one. HQE evaluates this one as not satisfying while LEED does not make any differences between the two configurations.

Table 3: SW-facing office: influence of a shading device.

		no shading device	fixed shading device
Lightsolve			
Lightsolve	average %	37% in range 19% too high 45% too low DGP = < 20% ; DGPmax = 29.2%	36% in range 9% too high 55% too low DGP = < 20% ; DGPmax = 26.6%.
HQE		GOOD (85% DF>1.5% and 100%>1%)	do not respond to the criteria
LEED		1 credit (100% area > 269 lux)	1 credit (100% area > 269 lux)

This first simple comparison shows that even if they go in the same direction as climate-based methods like Lightsolve, DF-based methods can lead to oversized windows inducing glare and overheating problems. As this observation is done for the Belgian climate, which is characterised by a majority of intermediate and overcast skies, this problem will be certainly more pronounced for other climate, presenting a majority of clear skies. The LEED criterion, which stays confusing as the absolute zenith luminance is not fixed, is easier to achieve but seems no sensible enough to be used as an optimization criteria at pre-design stage. Moreover, this method does not consider risk of glare.

Thus, rating systems should not be used as design tools. Indeed, they do not give accurate information needed for the optimization of daylighting design.

SATISFACTION AND VIEW OF DESIGNERS

User satisfaction was evaluated through a questionnaire filled by the architects (3 persons), the technical responsible of the VELUX*Belgium* Company and the thermal engineer. All these persons consider that daylight is very important in architecture projects. In average, they take daylight into account in 88% of their projects. According to their opinion, the major benefit of daylight is its impact on energy savings in buildings.

Generally, they consider daylight either intuitively or by using simple design tools. Some of them use more complex tools (radiosity for daylight factor evaluation or comparisons between several cases).

A goal oriented approach is in majority preferred. However, one of the architects prefers results presented in absolute values in order to compare this value with the reference standard values for electric lighting.

The temporal map graphical representation is appreciated, although the users report that it is not easy to understand and interpret it. The research team has been asked to create a tutorial explaining how to read the map. Concerning the importance of each graph or information, we saw a large disparity in preferences. Some users consider the "% too low" and "% too high" maps as fundamental and do not even consider the "% in range" map. Others prefer to look to the "% in range" map first and consider "% too low" and "% too high" as additional information, less important than all the others. As each map provided important information and as architects had difficulty to connect them together, a triangular scale (Fig. 10) was proposed for Lightsolve [10], which will result in the three maps being gathered into one (Fig. 11) in future analyses.

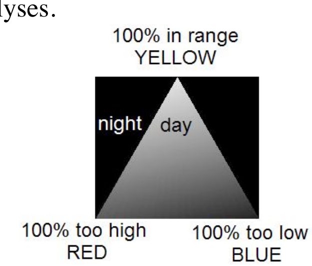


Figure 10: Triangular scale-grey scale for publication purpose

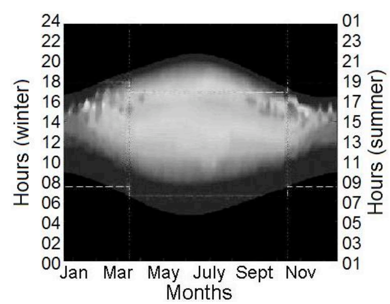


Figure 11: Illuminance map with the triangular scale -grey scale for publication purpose

Generally, the glare information is studied last. One person considers that all information has the same importance and that the results should be cross-analysed. If all the persons recognized that they have improved their knowledge in daylighting thanks to the project, none of them has analysed the results by himself. Mainly because it has already be done by the daylight expert team but also because it looked too complicated (for two of them). Finally, it was pointed out by some users that their decision to use Lightsolve for future projects will be conditional on the conviviality of the interface and the easiness of the results comprehension.

The questionnaire results also tends to show that people having more experiment with daylighting would consider Lightsolve more as a verification tool than as a design tool. The reason given is that in the frame of this study, the method did not consider special effects like “dramatization”, or the interaction between light and shade. However, this aspect of daylight will be soon studied through a PhD with the objective to introduce in Lightsolve a metric representing the daylight quality and interest of a space.

CONCLUSION

By comparison to the daylight evaluation suggested in LEED or HQE certification, the Lightsolve approach has the main advantage to consider glare problems and to fix a maximal illuminance value. The Lightsolve analysis is more accurate and sensitive than the two others and show when problems appear.

In the frame of the conception of the VELUX*Belgium* headquarters, the Lightsolve approach was appreciated by the designers as well as engineers. The goal oriented approach is, by a majority, preferred to an absolute value approach and the temporal map is appreciated even if it seems difficult to read. For that reason, we propose to create a tutorial explaining how to read and construe temporal maps.

This first application of the Lightsolve methodology on a real project highlights the difficulty for designers to interpret the results (by comparison between different configurations) and to give a priority order for design modifications. As daylight is only one aspect of the design process, designers do not have the time, and maybe the ability, to analyze the results by themselves and to give a priority order for the proposed modifications. The researchers working on the Lightsolve project are thus considering this problem by proposing to integrate in Lightsolve an expert system, using a hybrid combination of a knowledge-base and traditional optimization [7]. A simplified version of this approach can be found in the diagnostics offered by B. Paule in DIAL-Europe [11], based on fuzzy logic rules. Design improvements will be listed and rated in terms of efficiency in Lightsolve, in order to guide the designer in considering the global influence of the proposed change in the design.

The validation work also showed that it is essential to couple daylight information to solar gains and thermal information including target values as a function of the considered location’s climate, which is also a work underway. One of the architects pointed out that the quality of daylight and of daylit spaces was not addressed by Lightsolve. The creation of a metric dealing with that topic combined with the interest of daylit spaces has already been planned through a PhD work that will begin soon.

Finally, the work in collaboration with the architects showed us that it is really necessary to validate the Lightsolve approach through real projects. It is only during real design process that we can analyse how daylight can be optimized, taking into account the multidisciplinary of an architectural project. As a consequence, only a limited number of designers can assess the method. For that reason, it is necessary to continue the validation work on other real projects, in order to get opinions of other designers and improve the method. The objective is to answer to the needs of the majority of designers, in order to help them to optimize daylight in their buildings.

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