INTEGRATION OF LIGHTING PERFORMANCE INDICATORS INTO A DASHBOARD FOR DAYLIGHTING ASSESSMENTS

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ABSTRACT

The purpose of this study was to develop an integrated graph able to communicate to the designer -which is not specialist in lighting- a rating of the different indicators having significance when evaluating the daylighting conditions within a space, specifically, within classrooms. This graph integrates six daylighting performance indicators through a dashboard, allowing comparing a base situation with new architectural solutions. The dashboard has a five level performance scale, using colours in order to rate from the optimum until the most unfavourable scenario, translating a big amount of data and indicators into a single diagram. The different classroom's daylighting strategies were then summarized using the proposed dashboard, which allowed comparing the different daylighting performances achieved when using the proposed strategies.

INTRODUCTION

The appropriate use of passive design strategies in school buildings can highly diminish their energy use, improving its indoor comfort conditions and the learning environment for the students. Consequently, when the aim is to evaluate the impact a daylighting design strategy will have, computer simulations become a very useful tool. There are a series of daylighting indicators able to be obtained through a computer simulation, which favours the understanding of the resultant light within a space. Nevertheless, it becomes sometimes difficult to summarize and integrate these several different indicators in order to convey the strategy evaluation results to the designer. This becomes more important when the aim is to evaluate and choose among different design strategies.

Being aware of this issue, the graphical tool that is here shown was developed in an attempt to address it, within the context of an investigation on daylighting performance in school buildings. The aim of that research project was to evaluate the effect of different passive design strategies on the lighting performance of classrooms in different Chilean locations. Furthermore, to convey to the designer in a summarized and simple manner the effect of each strategy, allowing him to identify patterns that could help foreseeing the obtained results when utilizing one strategy or another, and therefore, to compare between the different daylighting strategies proposed.

DASHBOARD FOR DAYLIGHTING ASSESSMENT

Integrating lighting performance indicators for daylighting assessment

The proposed dashboard integrates six different indicators, which could help understanding the lighting performance a space will achieve. These are: Average Daylight Factor (%), Average Illuminance (lux) and Uniformity Ratio (-), together with complementary indicators such as Daylighting Autonomy (%), Surface in Range within the Target Illuminance (%) and Energy Demand (KWh/m^2 year) for the artificial lighting assessment. The first three indicators can be obtained through commonly used lighting simulation software, and the last three ones are easy to be obtained based on the illuminance calculation. Then, the target value for each indicator was established, based on the state of the art regarding to learning spaces within school buildings. Moreover, a five level performance scale was proposed, in an attempt to rate in which degree each lighting performance target was achieved when analyzing a space. Consequently, the achievement of the target values would lead to a good practice daylighting design.

Subsequently, the mentioned six indicators, together with their five-level performance scales, were integrated into a single diagram. The diagram was divided in six sections, where each section was associated with an indicator and its corresponding metric. The way of reading the proposed diagram is through the use of colour, where the colour green indicates that the target is fully achieved, whereas getting away from green means that the proposed designed strategy should be restated in order to meet the design objective. The colour red generates a warning, communicating that achieving that objective becomes unlikely (See Figure 1). Thus, this graphical tool, proposed as a dashboard, summarizes and conveys in a simple way the results obtained through a lighting simulation, allowing an overall understanding of the lighting performance of a space, and furthermore, to easily compare among different design strategies. The dashboard is partially based on the one proposed by Leslie, Smith, Radetsky, Figueiro, & Yue (2010), modifying the indicators and rating scales.

Figure 1: Proposed dashboard and colour rating scale, integrating six lighting performance indicators into a single diagram.

Daylighting goals and metrics integrated into the dashboard

The lighting indicators incorporated into the dashboard were analyzed in an independent manner, establishing a design objective for each of them, together with target values, which would indicate a good lighting performance in classrooms. Following, each indicator target, together with its metric and performance scale, are briefly explained:

Daylight Factor (DF): The objective pursued by this indicator is to achieve a percentage greater than 5% of the outdoor daylight getting into the classroom and falling on the students' working plane. This indicator allows quick comparisons of daylight penetration within the space under overcast sky conditions. It does not apply for other sky conditions. The proposed five-level performance scale is based on the one proposed by Bülow-Hübe (2001), which considers that artificial light may be needed when achieving a DF lower than 2%. On the other hand, when achieving a DF greater than 20%, extremely high illuminance levels may be obtained within the space, together with a high glare risk. Thus, it was considered that an acceptable intermediate level would be achieved when the DF ranges between 2 - 5%. This indicates that daylight may be enough for visual comfort, but artificial light might also be needed. Consequently, a DF ranging between 10 – 20% is considered as a good daylight level, but glare might also occur. Finally, the optimum range is located between 5 – 10%, which indicates that the working plane would be properly lit, allowing daylight autonomy within the classroom (see Table 1). It is important to clarify that DF does not apply to skies other than overcast, in which case the indicator is shown in colour grey.

Table 1: Daylight factor performance scale.

DF %	< 2	> 20	2-5	10-20	5-10

Average Illuminance (E_{av}): The proposed objective for this indicator was to be able to deliver a sufficient quantity of daylight for carrying out different visual tasks within the classroom. The limiting values for the performance scale were stated according to the Illuminating Engineering Society (IES) (Rea, M.S, 2000) proposal. It was considered that low average illuminance levels would require supplementary light, and excessively high E_{av} could provoke glare. Thus, the scaling was done as following: when having an average illuminance below 200 lux (red), it might be impossible to perform visual tasks without complementary artificial light. On the contrary, when having extremely high average illuminance levels, e.i. above 5000 lux (dark orange), carrying out visual tasks may be impeded by glare. This could also indicate that the windows area is too high. Consequently, an E_{av} ranging between 2000 – 5000 lux indicates that it may fall too much light on the working plane, and therefore, a solar control strategy might be needed. On the contrary, an E_{av} between 200 - 300 lux indicates that there might be times within the analyzed period where the daylighting levels would be too low, so the windows size and glazing type should be checked. Finally, an E_{av} between 300 – 2000 lux indicates that there should be enough daylight for performing common visual tasks within the classroom, with no need of using artificial light for visual comfort (see Table 2).

Table 2: Average illuminance performance scale.

E_{av} (lux)	<200	>5000	200 - 300	2000 -5000	300 - 2000

Surface "In Range": This indicator is based on the evaluation of the illuminance ranges predicted within the space, allowing to size the percentage of the classroom area which would achieve the proposed design objective (Bodart & Andersen, 2008). Hence, it is the total classroom's area meeting the needed illuminance level for visual tasks on the working plane, being the design objective to achieve the target illuminance in most of the classroom's area, avoiding too dim or too bright zones. Thus, in concordance with the previous indicator, the optimum illuminance range would be from 300 to 2000 lux. The best scenario would then be to achieve above 80% of the classroom's area within the previously mentioned illuminance range. This would indicate that most of the classroom's area is well lit, with high daylight coverage. On the other hand, when less than 20% of the classroom's area achieves illuminance levels "in range" on the working plane, a considerable proportion of its surface would be expected to be poorly lit, with low daylight coverage. The ranges between high and low coverage were proportionally scaled, in order to convey in which percentage the design objective is met (see Table 3).

Table 3: Surface "In Range" performance scale

In range %	<20	20-40	40-60	60-80	>80

Uniformity Ratio: This indicator evaluates in which proportion a homogeneous illuminance is achieved within the classroom. It is calculated as the ratio between the minimum and the average illuminance predicted for a certain space, being the design objective to obtain an equilibrated daylight in the working plane, without significant variations on the illuminance levels for visual comfort. The proposed target value is to achieve a uniformity ratio greater that 0.5 (green), in concordance with what it is stipulated by the EN 12464-2 (European Committee for Standardization, 2007) .This value would indicate a uniformity relation that allows an adequate contrast with daylighting. For the intermediate ranges, the Building Bulletin 87 (Architects & Building Branch, 2003) proposal was adopted, which establishes that side-lit classrooms should achieve a uniformity ratio of at least 0.3 to 0.4. Hence, the range between 0.4 and 0.5 would be an acceptable uniformity, and the range from 0.3 to 0.4 would be the intermediate one. Finally, values below 0.3 would indicate that zones with too much contrast would exist, negatively affecting visual comfort. This last range was also divided in two levels, for a better understanding of the daylight uniformity performance (see Table 4).

Table 4: Uniformity ratio performance scale.

Uniformity (-)	< 0.2	0.2 - 0.3	0.3 - 0.4	0.4 - 0.5	> 0.5

Daylighting Autonomy (DA): This indicator shows the percentage of the analyzed period where daylight is enough for achieving the target illuminance on the working plane. The design objective is to obtain adequate daylighting autonomy, avoiding the use of artificial light during the occupancy period. Consequently, the minimum illuminance of 300 lux stated as the target value for the previous indicators was considered as the benchmark. Thus, the proposed target value for DA was settled as an 80% of the occupancy time (Leslie et al., 2010). Predicting a DA above this percentage would indicate that daylight would be enough during most of the occupancy time for achieving visual comfort. Therefore, it also indicates that a high energy saving potential could be obtained. On the contrary, the worst case scenario (red) was established when DA is less than 20% of the occupancy time, which indicates that most of the time it would not be possible to achieve the target illuminance through daylight. In this case, a low energy saving potential is therefore expected. The values ranging between the best and the worst-case scenario were proportionally scaled, regarding the daylighting autonomy percentage achieved for the analyzed period (see Table 5).

Table 5: Daylighting autonomy performance scale.

DA %	<20	20- 40	40 -60	60 -80	> 80%

Energy demand (ED): The design objective in this case is to achieve the minimum energy demand for artificial lighting possible. Thus, this indicator allows predicting what would be the energy requirement for artificial lighting within the analyzed period. In order to do this, the total amount of time where artificial light is required for achieving the target illuminance value (e.i. 300 lux) has to be calculated. Then, in order to be able to settle a target value, a high efficiency lighting system was assumed. Its lighting power density was considered 11.25W/m^2, for an occupancy period from 8am to 12pm and from 1pm to 4pm. For an annual analysis, the winter and summer holidays were also taken into account. It was also assumed that the system would provide 300 lux in the middle point of the classroom. Thus, the green colour indicates that the classroom would have a low lighting energy demand, utilizing less than a 20% of the analyzed time artificial light during the school's occupancy period. On the contrary, red indicates that more than 80% of the time artificial light may be needed in order to achieve visual comfort. In a similar way as in the previous indicators, the performance levels were proportionally scaled between the best and the worst-case scenario, conveying through this way how far the analyzed space would be from achieving the minimum energy demand calculated for that space (see Table 6).

Table 6: Energy demand performance scale

LED KWh/ m²year	> 12	12 - 9	9 - 6	6 - 3	< 3

APPLICATION OF THE ASSESSMENT TOOL

Lighting simulation parameters

The aim of the study was to evaluate the daylighting performance achieved within classrooms in ten different Chilean cities, considering two different sky conditions regarding the prevailing skies for each location, and to propose and evaluate design strategies for improving that daylight performance. The daylighting assessments of the different strategies to be evaluated were carried out using RADIANCE software. For each location, two sky conditions were simulated, according to the sky types defined by CIE (Commission International d'eclairage, 2003). For the Chilean cities located between the latitudes 18º South and 27º South, where clear skies prevail, clear sky (c) and intermediate sky (i) were simulated, whereas in the cities located between latitudes 33ºS and 53ºS, overcast sky (o) and clear sky were assessed. The illuminance prediction within the classrooms was obtained placing a horizontal grid, compounded by 12 sensors, symmetrically distributed, located on the students' working plane. Due to the amount of simulations needed to be performed, an annual analysis was carried out, simulating key moments of the year, such as the equinoxes (March 21st / September 21st), the winter solstice (June 21st) and the summer solstice (December 21st). For each of these key dates, three times of the day were evaluated: morning (9am), noon (12pm) and afternoon (3pm), in order to have a complete overview of the lighting performance achieved through the school's study day. (In Chile, a normal study day is from 8am until 4pm). In total, 9 different representative moments of the year were predicted. It is worth mentioning that the assessment tool that is here presented can also be applied for evaluating periods different than a year, for instance, seasonal or daily analysis.

Subsequently, the obtained data for each point on the grid was utilized as the input for evaluating the previously explained six indicators. The results shown in the dashboard that is here presented are the annual averages obtained through the simulations performed on the 9 key moments of the year, for each indicator. The dashboard was created using MATLAB software, through a script designed for reading and processing the obtained data, allowing to build the integrated diagrams in a fast and precise manner for each of the proposed design strategies in every studied location. Through this way, more than 90 diagrams were built in little time, allowing displaying the big amount of data obtained through the lighting simulations in a fast and handy way.

Following, the results obtained for one of the evaluated prototypes is presented, in order to show the method of using and reading the proposed dashboard. The example is a typical classroom located in Santiago, Chile. It is an oversized double-loaded corridor structure, north-south oriented. It can be noticed on Figure 2 that internal and external light shelves were placed on the windows, aiming to block direct sunlight penetration and to control glare. Additionally, the corridor was considered as an indirect daylighting source, both for the north-facing and south-facing classroom.

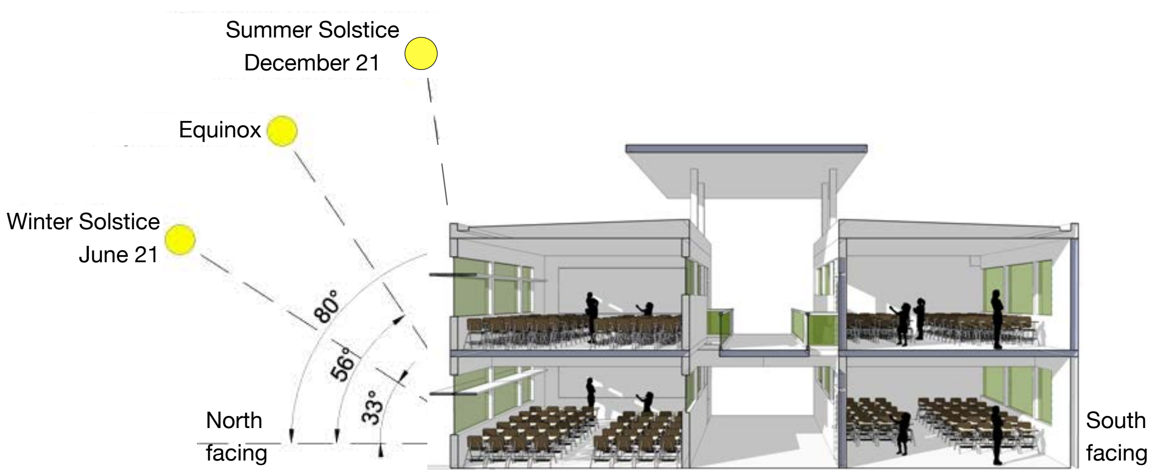

Figure 2: Oversized double-loaded corridor classrooms prototype proposed

Dashboard contribution's to architectural design

When using the proposed dashboard, the designer is able to understand the lighting performance achieved for a case study through the rating of six different indicators. This also allows comparing the effects obtained when using different design strategies, to test, for instance, the effectivness of certain shadding devices, and/or to assess the building in its different orientations. Hence, this dashboard is a conceptual tool that allows obtaining an overview of the daylighting performance of a space in a certain climate.

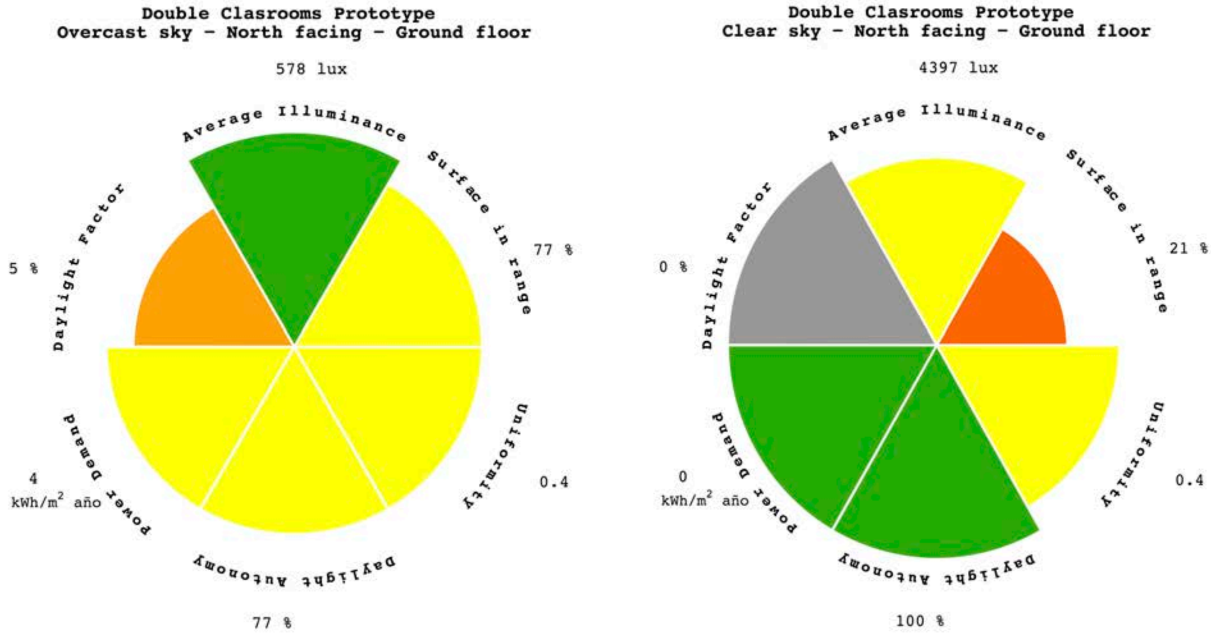

Figure 3: Simulation results for the North-facing classrooms on the Ground floor

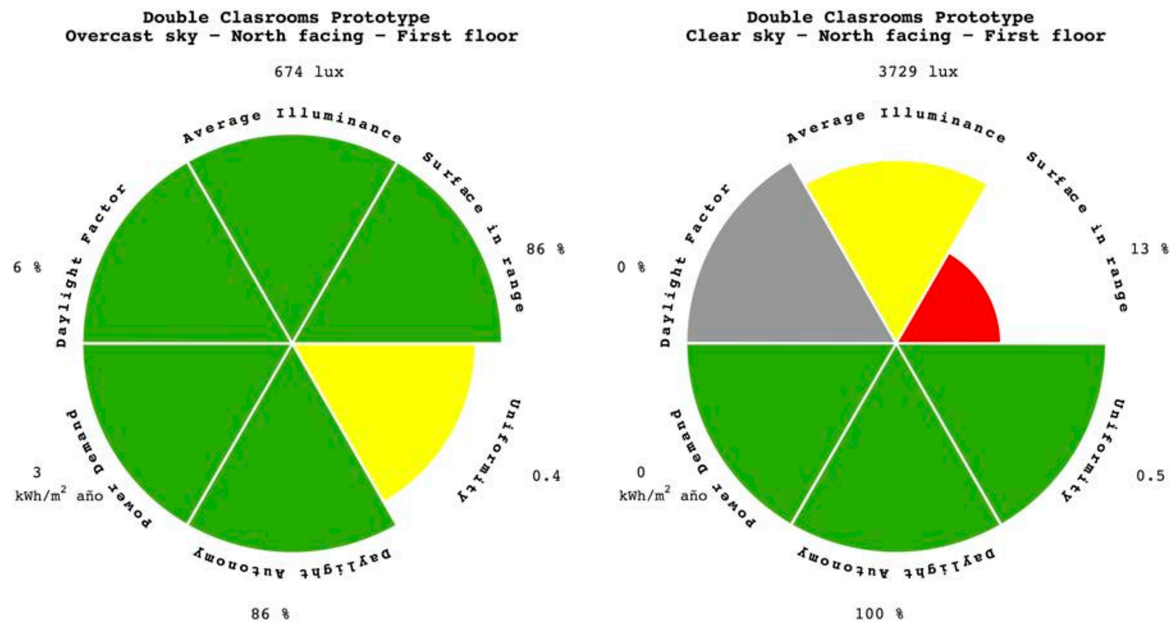

Figure 4: Simulation results for the North-facing classrooms on the First floor

When observing the dashboards obtained through the propotype simulations (see and Figure 4), it is possible to compare what occurs in the same classroom when clear or overcast sky, in any of the two analyzed storeys. Thus, it can be easily observed if the design strategy is close or away from achieving the design objective stated for each of the six indicators. The tool has two complementary lectures, being the first one related to the colour and the second one conveying the obtained numerical result for each indicator.

If analysing the prototype results, it can be noticed that the ground floor classrooms are not able to meet most of the design objectives, being the 'Average Illuminance' the only one achieved in both cases. When simulating with clear sky, it can be read from the dashboard that even though the 'Daylight Autonomy' was achieved in a 100%, the designer might have to consider a solar control strategy. This, since the predicted E_{av} is too high and moreover, because the 'In Range Surface' is only 21%, which implies that almost 80% of the classroom's area would have illuminance values above 2000 lux. With regards to the 'Uniformity', it can be noticed that is not possible to achieve the target value. For the same case, it can be observed that 5 out of the 6 integrated indicators would be achieved within the first floor classroom when overcast sky conditions. Therefore, using the proposed dashboard allows drawing conclusions regarding the achieved daylighting performance of the assessed prototype, demonstrating for instance that the daylight contribution of the corridor is not enough for achieving an adequate uniformity on the working plane.

CONCLUSIONS

The use of the daylighting dashboard that was here presented can highly benefit the design process, facilitating making decisions with regards to daylighting strategies. This was demonstrated when applying this tool in assessing the effectiveness of several design strategies proposed for improving the daylighting performance in classrooms located in different Chilean cities. In that study, the aim of conveying in a simple and summarized way the results of a big sample of simulations was fully achieved. Moreover, the use of the dashboard allowed orientating the non-specialized architect regarding the results that may be obtained when using the proposed strategies, creating guidelines for a good practice daylighting design in the 10 Chilean cities which were evaluated.

With regards to the objective of creating an integrated assessment tool, it can be said that the use of the dashboard made possible conveying in a combined manner the results of a lighting evaluation, taking into account different parameters related to visual comfort. Furthermore, this tool allowed comparing different prototypes and strategies in different locations and orientations. In relation to the dashboard ability of summarizing a big scale study results, it can be concluded that it allowed handling the big amount of data obtained when performing daylighting simulations. It is also possible to incorporate more indicators into the dashboard, when need it for a better understanding of the resulting daylight within a certain space.

Finally, it worth mentioning that this dashboard can be applied in designing, assessing and verifying new daylighting strategies in buildings other than schools. However, in order to do this, the metrics and goals for each of the indicators should be adjusted, redefining the performance rating scale for each indicator, regarding the visual tasks that would be performed in the building to be evaluated.

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