Climate-based daylight simulation as a planning aid for the design of solar facades

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Abstract

Climate-based daylight simulation allows performance predictions for façade designs based on available climate data. Simulations based on daylight contribution coefficients coupled with models of sky luminance distribution make this tool available even in the design process. Metrics describing glare probability and the potential to substitute electrical lighting by daylight are applied and design proposals iteratively improved. The method is demonstrated on an existing building, the “Neubad Lucerne”, which is subject to design studies by students of architecture. Proposals to extend the two South-facing facades are developed, aiming at lower glare probability and optimized use of daylight to minimize electrical energy consumption for lighting. This paper shows:

a) The different façade designs in photorealistic renderings.

b) The quantitative analysis of useful daylight illuminance and daylight glare probability.

c) A comparison of the designs according to the predicted daylight glare probability.

Finally, It closes wih a comment on using climate-based simulation as a design tool.

Keywords: climate-based daylight simulation, useful daylight illuminance, simulation.

1 Introduction

Controlled use of daylight is crucial for solar architecture. Controlling and redirection of daylight can help saving electrical energy for lighting and reduce glare and excessive solar irradiation leading to unwanted overheating. However, few planning aids for solar facades provide reliable quantitative and qualitative performance predictions. Often simplified calculation methods are used, which usually are not able to account for the benefits of advanced solar facades.

The “Neubad Lucerne” is going to be converted from a swimming facility to a cultural centre and workspace for creatives. Reduced glare, solar control to limit heat loads, and a still high level of daylight illuminance are required, leading to a retrofit of the existing façade. Proposals for that retrofit must reflect the character of the existing building as well as the creative potential of its occupants. Architecture students were asked to develop proposals for the South-facing facades to meet these requirements. To quantify the effect of their design proposals and to allow an iterative improvement during the design process, climate-based simulation was used as a tool to predict the selected performance metrics Useful Daylight Illuminance (UDI) [1] and Daylight Glare Probability (DGP) [2].

2 Climate-based daylight simulation

2.1 Sky and building models

Simulation is an established method to assess the expected performance especially in maintaining a thermal comfort at acceptable energy consumption, and to help optimizations during planning and dimensioning of buildings. To predict the typical overall performance of a building, hourly climate data of a typical meteorological year (TMY) as available from weather stations all over the world is used. The hourly records in such weather data usually includes direct and diffuse illuminance. The sky luminance distribution at a given time as required for daylight simulation is reconstructed using the recorded measurements and a model such as the Perez All Weather Sky [3].

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All relevant parts of the building and its neighbourhood are geometrically modelled and linked to material descriptions. The geometric model and its material characteristics are converted into the native scene language of the lighting simulation software Radiance.

2.2 Simulation with Daylight Contribution Coefficients

Climate data of one TMY contains thousands of hourly illuminance measurements, each leading to a different sky luminance distribution and thus a different sky model. Running one separate, raytracing-based simulation for each hour of a year would be too time-consuming for a planning tool. To reduce computing times, daylight contribution coefficients are calculated in one time-consuming, first step and combined with sky luminance distributions in a computing-wise inexpensive second step for each hour.

The sky hemisphere is subdivided into patches of approximately equal area. Imaginary sensor locations, where luminance or illuminance readings are to be recorded, are defined. For each sensor and each sky patch, the fraction of light received by the sensor related to the total amount of light emitted from the patch are calculated. The calculation of these Daylight Contribution Coefficients (DCC) [4] for each patch and sensor is supported by the raytracing tool rcontrib, which is part of Radiance. DCC as fractional values do not include any information on any sky luminance distribution and are dependant only on the model geometry and material characteristics.

For one TMY, each hourly sky luminance distribution is binned into the patch model used to calculate the DCC. The Radiance-command genskyvev supports this step and provides a range of patch schemes and resolutions. The resulting vector of patch luminances is than multiplied with the vector of DCC for each sensor. Radiance provides the command dctimestep to support this multiplication, supporting both single-point sensor readings and images (luminance or illuminance maps) as output. The result of this multiplication is the sensor value for the given time. This multiplication is repeated over all hours of the TMY and over all sensors.

3 Application of performance metrics

The described method based on DCC can provide both hourly illuminance and luminance values. A simple assessment would follow a more-is-better approach and could sum up or average the reading for a full year as a representation of a typical annual exposure to daylight. However, linking illuminance and luminance to requirements and occupants behaviour leads to a threshold-based approach.

3.1 Illuminance-based metrics

For illuminance, several states are considered for the internal lighting such as purely electrically lid, combined electrical and natural lighting, lid only by daylight and overlid with probably discomfort problems and potential user reaction such as shading activation. We apply the Useful Daylight Illuminance (UDI) developed to account especially for overlid hours and time intervals were daylighting is not sufficient but able to contribute and reduce electrical lighting demands. The illuminance ranges and their corresponding rating is given in table 1.

Useful Daylight Illuminance (UDI)		illuminance range [lux]	
UDI rating	**short**	**min.**	**max.**
fell-short	UDI-f	0	100
Supplementary	UDI-s	100	300
Autonomous	UDI-a	300	3000
Exceed	UDI-e	3000	∞

Table1 : Useful Daylight Illuminance (UDI) categories and corresponding illuminance ranges.

We visualize the UDI for one year using heatmaps, where the axes correspond to day of year and time of day. To account for the requirement of uniform daylight illuminance, the spatially resolved illuminance values are not averaged. Instead, the fraction of area where the given UDI criteria are fulfilled are mapped on the heatmap, allowing quick analysis of temporal patterns.

3.2 Luminance-based metrics

Luminance maps (which can be seen as photorealistic images with photometrically unbiased values) are compiled into glare ratings expressed as Daylight Glare Probability (DGP). Luminance maps covering a field of view of 180 degress both horizontally and vertically are required, as the vertical (eye) illuminance needs to be calculated by integrating the luminance map over the hemisphere. The software tool evalglare is used to process the luminance maps, calculate glare ratings and overlay potential glare source over the luminance map. In this case study, glare analysis was not performed on an hourly base, but for one given view and one time. The result is one DGP value and an image identifying the potential glare sources, allowing students to improve their design accordingly.

4 Application on “Neubad Lucerne”

4.1 Current state

The South-facing facades of the hall of the former large swimming pool of “Neubad Lucern” is the subject of the design studies by architecture students (figure 1). The current double glazing is held by alumium profiles and is to be kept intact. External sunshade fabrics used to be operated to prevent excessive solar irradiation in summer but are dysfunctional now. The ceramic surfaces of the pool and perimeter floor are bright white and specular, leading to strong reflections of direct sunlight entering the building interior. The roof has an overhang to all sides, concrete columns stand free on the outside of the façade. A horizontal beam divides the glazing into two horizontal zones.

4.2 Design proposals

Designs for additions to the façade were developed by seven groups of three to four students each. During one term, three iterations of designs, simulations and analysis were performed. An overview on the range of designs for the last iteration is given in figures 2-8. Only one of these proposals (figure 5), is to be presented in detail here.

The proposed design consists of an array of shelf-like, external structures. The depth of the shelf-system prevents direct sunlight entering the interior of the building, while its diffuse, reflective surfaces reflect partially reflect the direct sunlight into the interior. The largest depth of the structure is in the upper third of the façade, where the probability of direct visibility of the sun is highest. The topmost row, which is located below the overhang of the roof, has a reduced depth, as well as the lower rows where direct sun visibility is not expected due to occlusion by neighbouring buildings.

The DGP (figure 9) as computed from the fisheye image (figure 10 “Gruppe 4”) is still high at about 0.5, but better than most other designs. The extreme perspective chosen should however be considered, Improvements could include changing the highly reflective surfaces of the bright white ceramic tiles. The fisheye-view shows that the direct visibility of the sky in upper third of the façade is blocked to a large extend, promising reduced glare by directed sun visibility. For perpendicular view directions, the obstruction by the shelf-structure is neglectable, allowing to view through the façade. For a view from the bottom of the pool, potential glare sources as marked remain in the unobstructed parts of the sky, which, however have been largely reduced by the proposed design.

The heatmaps for the four UDI categories (figure 11) indicate that the currently experienced overexposure on sunny days has been eliminated by blocking direct sunlight entering the room. The heatmap mapping UDI-a over a TMY shows that for all seasons, almost the whole area achieves horizontal workplane illuminance in the range of 300 lux to 3000 lux during daytime.

5 Conclusion

Climate-based daylight simulation helps students to evaluate and improve their designs by iteratively developing proposals to match given performance criteria. While the simulation were carried out by experts, importing only the variable components of the façade allowed to support students during the design phase. Communication of annual results to architecture students is a challenge, but the concept of heatmaps allows to understand annual performance. While hiding temporal information, for the designer, an integraded “performance value” for the whole year would still be more practicable.

Figure 1: Current state of the former pool hall.

Figure 2: Patches of fabrics of constant transmission (T=0.15) but varying reflection.

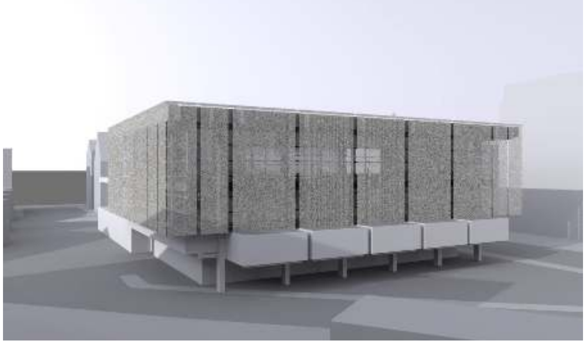

Figure 3: Metal mesh structure wrapped around the façade including edge of the roof.

Figure 4: Several layers of fabrics in front of the glazing, R=0.25, T=0.50.

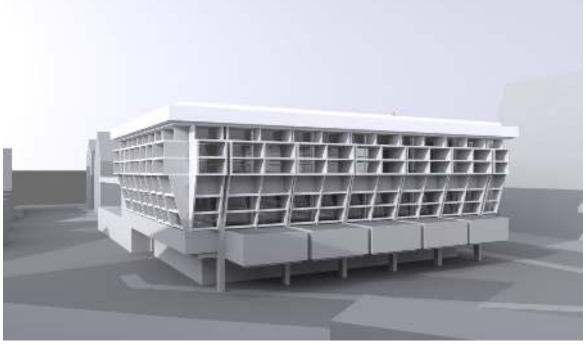

Figure 5: Array of shelf structures with varying depth.

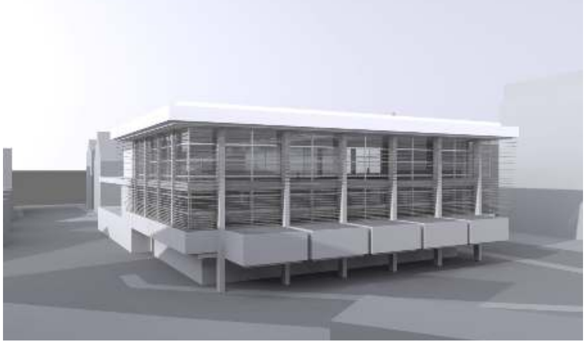

Figure 6: Fixed, tilted external blinds. Big horizontal light shelf on the inside.

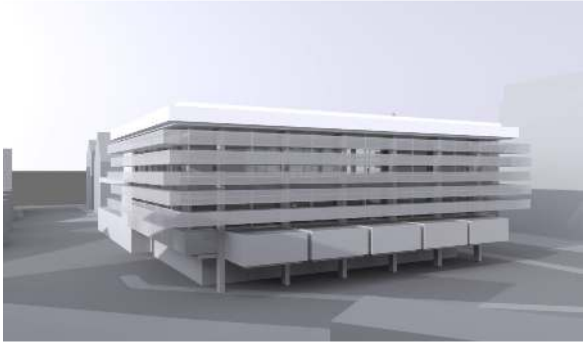

Figure 7: Stack of hollow, translucent shades made of fabrics.

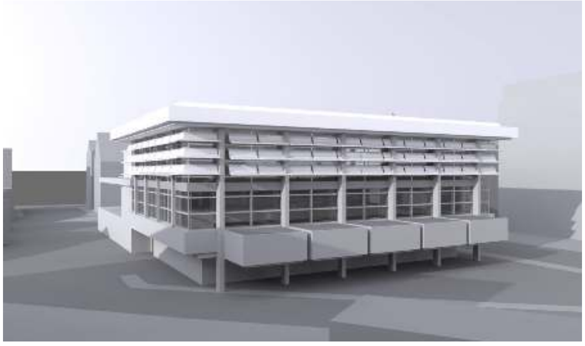

Figure 8: Reflective wings. Highly reflective, diffuse coating on fabric.

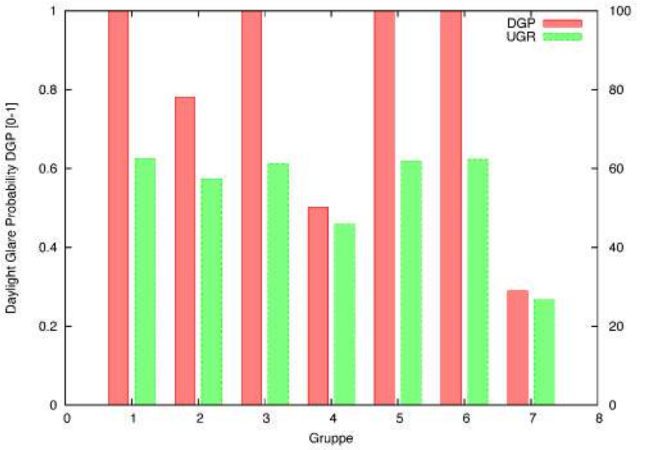

Figure 9: Comparision of the daylight glare probability (DGP) for proposed design variants (UGR as a reference).

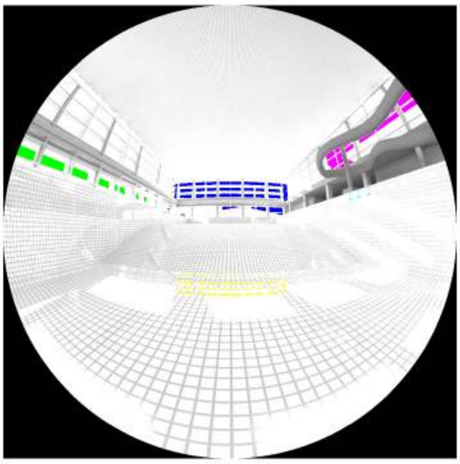

Figure 10: Potential glare sources for the same façade design.

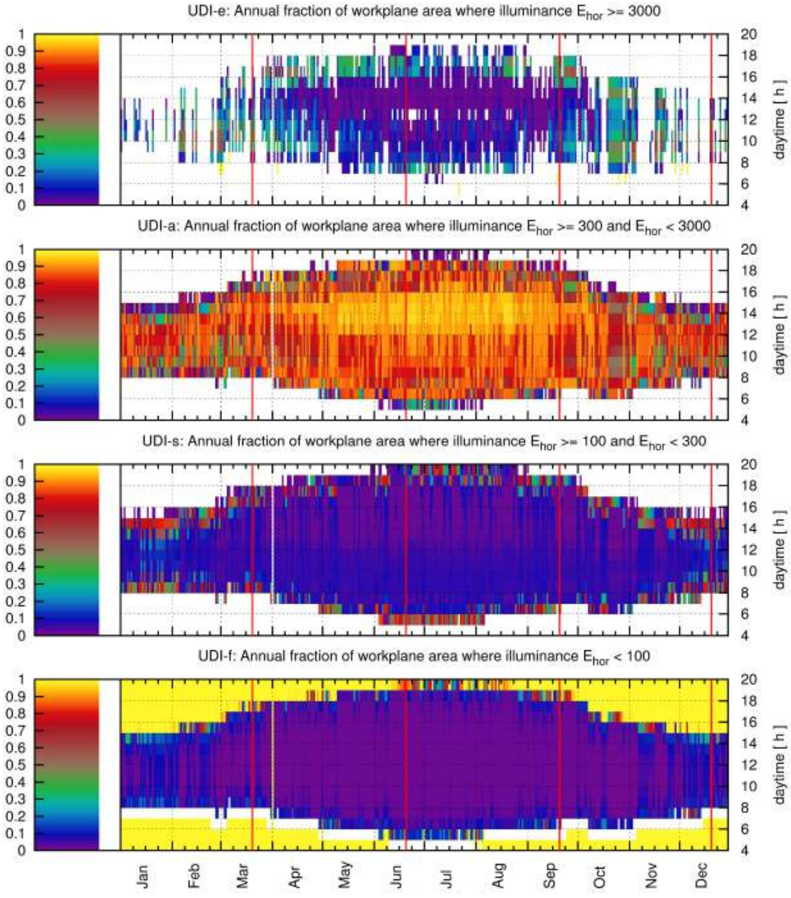

Figure 11: Heatmaps showing fraction of workplane area in building perimeter meeting UDI criteria.

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