THE ASSESSMENT OF DAYLIGHT REFLECTION FROM BUILDING ENVELOPES

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ABSTRACT

Buildings could influence surrounding microclimate with their envelope designs. Reflective surfaces on the building envelopes could reflect daylight to the neighbourhood and cause problems such as glare and overheating. For the surrounding drivers, pedestrians and building occupants in the area, the reflected sunlight from the building envelope becomes the bright spot in their view which results visual discomfort or impairment. For building envelope designs, it is important to analyse the effect of daylight reflection to the neighbourhood at design stage. This could reduce the risk of environmental problems and minimize the consequences cost after construction.

A software tool to evaluate the reflected daylight from building envelopes has been developed. It is implemented on parametric design platform GRASSHOPPER using RADIANCE as background simulation engine. As shown in the case study, using the tool, the form of the assessed building envelope could be analysed and the critical areas around the assessed building including roads, pavements and façades of neighbouring buildings are examined for potential concentration of reflected daylight. Rich information is recorded for the critical areas: annual reflected solar radiation, period with irradiance value above threshold, origin of the reflected daylight on the assessed building envelope, etc. This information could help designers to optimize the form of the envelope and make façade material selection. The tool shows potentials for architects to understand the impact of their designs and avoid potential environmental problems.

Keywords: simulation, daylighting, building envelope, reflection, RADIANCE

INTRODUCTION

Buildings could affect surrounding microclimate with their envelope designs. Reflective surfaces on the building envelopes could reflect daylight to the neighborhood and cause problems such as glare and overheating. For the drivers, pedestrians and building occupants in the area, the reflected sunlight from the building envelope becomes the bright spot in their view which may result visual discomfort or impairment. With development of new glazing technologies, glass is increasingly being used on building envelopes. Additionally, in order to achieve the goal of energy conservation and lower the cooling load, glazing with high reflectance is preferred by façade designers. Both of these contributed to the more frequently encountered problems of reflected daylight from building envelopes. Another issue may lead to the problem of reflected daylight is the design of free formed or curved envelope. Without careful analysis, reflective materials on the curved surfaces could magnify sunlight in the same way as solar concentrators and cause problems more than annoyance to immediate neighbors. In extreme cases, scorched people's hair or even melted plastic cups are reported [1].

In literature, many approaches to evaluate and prevent the hazard from reflected daylight can be found. Planning authorities have enacted regulations to eliminate the problem of reflected daylight from building facade in several countries, mainly by controlling the use of building materials based on their reflectivity alone [2,3,4]. In practice, problems may rise because of such regulations. The policy may be possibly too restrictive with material selection, particularly in cases where proper architecture design can offset the additional reflected daylight from the envelope. In academia, researchers also developed methods to evaluate the effect of reflected daylight from building envelopes [5, 6]. These methods could only analyze a limited number of viewpoints in the simulation step and as a result, it is possible that viewpoints with severe glare problem in the neighboring area are overlooked. Building professionals also established methods to assess potential solar hazard from the proposed development in response to the requirement in building regulations. One methodology is widely adopted by Australia building consultants [7]. The application of this method is limited to constructed buildings and thus could not predict potential problems from reflected daylight in the design stage. This approach however ignores the duration of time over which reflections occur to the neighboring building.

With the aim of overcoming most of the drawbacks explained above, a new software tool for the evaluation of the reflected daylight from building envelope has been developed. Each building envelope design could be evaluated in the design stage. It allows detailed description of the assessed building envelope and the neighboring buildings with material reflection property. Positions in the neighborhood where reflected daylight is concentrated could be identified by the algorithm. With selected positions as viewpoints, using annual weather data in simulations, each time period when reflection occurs could be detected. The tool could also record the origin of the reflected daylight from the assessed building envelope and display it on the 3D model.

The tool presented may help architects to have a better understanding of the environmental impact of the building envelope at design stage. Additionally, it also provides information for designers to modify the form of the envelope and make material selections.

METHOD

For the task to assess reflected daylight from building envelopes, the presented method combines the two most commonly used lighting simulation method: forward ray tracing and backward ray tracing. Forward ray tracing method is more efficient in the situation to identify the areas in the neighborhood which are affected by the reflected daylight from the assessed building envelope. It could trace the whole transmission process of daylight: emission from the sun - reflection on the assessed building envelope – terminates on neighboring buildings. The distribution of reflected daylight from building envelopes follows angle of incident as well as ambient weather conditions and seasonal differences. Therefore, it is necessary to evaluate reflected daylight with annual weather data. Backward ray tracer in RADIANCE provides an efficient way for time-series simulations using daylight coefficient method [8]. It could avoid redundant computations and improve the overall speed of annual simulation by a large factor.

The working procedure could be divided into four steps. In the first step, the assessed building envelope and the neighbourhood models are required with their material reflection property. The next step is to localize reflected daylight distribution in the neighbourhood using forward ray tracing method. The critical positions are identified by density of intersections between reflected daylight and neighbouring buildings. This step works as a pre-selection step for following backward ray tracing procedures and it also ensures that all positions in the neighbourhood where daylight is concentrated could be identified. The third step is to quantify the reflected daylight received at the critical positions with annual simulation. In the last step, the annual simulation result from the previous step is further processed to extract information of the origin of the reflected daylight on the assessed building envelope. With all the information from the above evaluation process, designers could modify the envelope design accordingly by changing the form, materials, orientation, etc. The design-evaluation process could be repeated until the design target is achieved.

CASE STUDY

Step 1

The presented reflected daylight evaluation tool has been applied to analyse performance of a building with curtain wall facade. The assessed building is located in Zurich and covered with a full glazing envelope. The model has been created in RHINO together with the neighbourhood. The assessed building envelope has been modelled with Double Pane Low-e glazing assuming reflectance of 29.3%. The neighboring buildings are 35% diffuse reflectors and the reflectance ground has been set to 20% (see Figure 1).

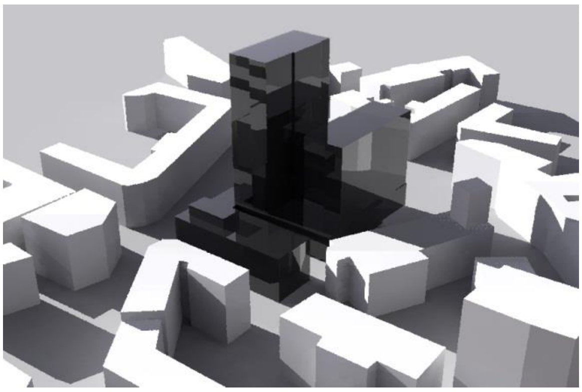

Figure 1: The assessed building with glazing envelope and the neighbouring buildings.

Step 2

With Zurich's sun path, forward ray tracing process has been carried out using half-hour time step throughout one year. Figure 12 (left) demonstrates the ray tracing process for one time step with reduced number rays while in the actual simulation, 10000 rays has been used for each time step. Figure 12 (right) shows the distribution of reflected daylight in the neighbourhood and 7 critical positions which have the highest density of ray intersections has been identified. Position 2 and 5 are located on the roof of the neighbouring buildings while the other positions are on the facades.

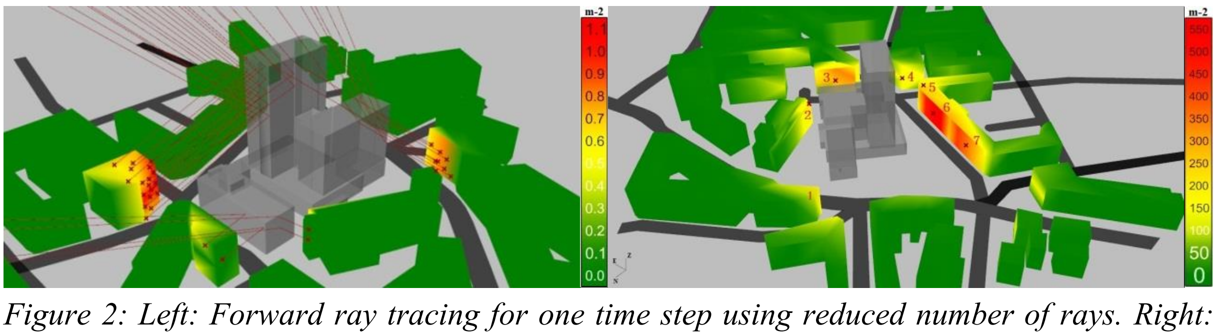

Figure 2: Left: Forward ray tracing for one time step using reduced number of rays. Right: Colour coded intersection density (number of intersection per square meter) for one year with critical positions numbered and marked with red crosses.

Step 3

With critical positions identified, the climate based simulation has been performed with luminance distribution of the sky according to measured data in Zurich and CIE clear sky model. The result with the sky model assumes sunny sky over the whole year which represents the worst case scenario for reflected daylight from the assessed building envelope. The simulation using weather data addresses the influence of weather condition for the location of the building and therefore it could be used to predict the reflected daylight in a local context. Some of the simulation results are presented in Figure 3. Position 2 receives the highest intensity of reflected daylight among all the tested positions because it is located the closest to the assessed building which constitutes a large part of the view at position 2. Position 3 only receives excess reflected daylight in the early morning. The reason consists in the fact that this position locates opposite southeast facing façade of the assessed envelope. Reflected daylight could only reach position 3 when the sun is to the east of the façade. Position 6 receive large amount of reflected daylight throughout the year around 3pm. This explained the high intersection density at position 6 in Figure 2. In the afternoon, intensive daylight is reflected by the southwest facing tower block toward the façade where position 6 is located.

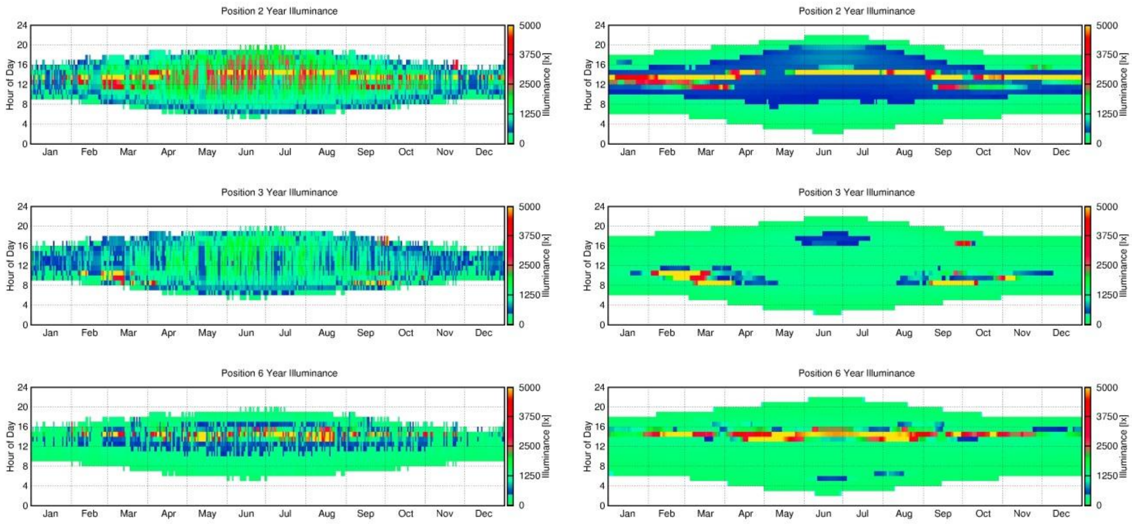

Figure 3: Heat maps of illuminance contributed from reflected daylight received at critical positions 2, 3 and 6 using Zurich weather data and CIE clear sky model.

Step 4

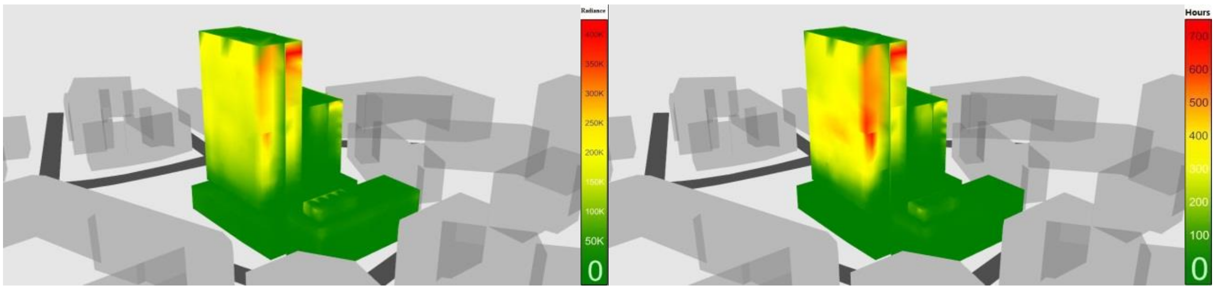

Figure 4: Left: Colour coded cumulative radiance on the assessed building envelope. Right: Hour count of luminance above threshold of 10000 cd/m^2 displayed on the assessed building envelope

After further processing of the time-series simulation results, the cumulative radiance of the reflected daylight from the assessed building envelope is calculated and displayed on the model (see Figure 4 left). The southwest facing façade of the tower block reflects intensive daylight and the extreme values occur at the highest levels of the southeast facing façade. The effect of the daylight reflection is also evaluated by counting hours when luminance is above threshold of 10000 cd/m^2 (see Figure 4 right). The color coded pattern is very close to the radiance distribution pattern in Figure 4 (left). The difference is that highest values are located around the medium height on the building rather than the highest levels.

Designers could focus the optimization work on the identified areas with extreme values in Figure 4. Whether to choose results from cumulative radiance assessment or radiance above threshold depends on the function of the neighbouring buildings and the potential effect of the reflected daylight.

CONCLUSION

A software tool for the assessment of reflected daylight from building envelopes has been developed. It overcomes the drawbacks of the existing assessment methods. Detailed model for the assessed building envelope and the neighboring buildings are accepted. Material reflection property is emphasized for the building models which should be based on verified or measured material models. Forward ray tracing is introduced to the evaluation procedure as a pre-processing step for the following annual simulation. It could identify all critical positions in the neighborhood where daylight is concentrated and make the later steps more efficient. Both weather data and CIE weather model could be used for the time-series simulation. For all viewpoints assessed in the neighborhood, rich information could be recorded including annual irradiance values contributed from the assessed envelope, period with irradiance value above a threshold, origin of the reflected daylight on the assessed building envelope, etc. With the assessment results displayed on the 3D model using color scale, designers could identify the critical areas on the envelope quickly and adjust the envelope design accordingly.

Further improvement of the presented method is possible. The assessment result could be linked to algorithms for mesh modification. With this feature, the whole design-assessment process could be repeated automatically. Ideally, the improved method could suggest optimized envelope design in which minimal modification is involved. Validation of the assessment results with more case studies is also planned.

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