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Estimating the annual range of global illuminance on a vertical south facing building facade

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Abstract
Towards assessing the daylighting potential for a campus building and in consideration of the recommended strategy of maximizing window exposure on south-facing walls in northern latitudes, the range of global illuminance on a south facing vertical surface at the building location was estimated over an annum, under both clear and cloudy sky conditions, using a calculation methodology proposed by the Illuminating Engineering Society of North America. The illuminance is observed to be a variable over the day with the daily variation estimated to range as high as 35KLx, over the year and under different sky conditions. Overall, it is estimated that the dynamic variation of global illuminance on a south facing façade,specific to the study location, ranges from 14KLx to 100Klx.

Keywords: Daylighting; Global illuminance; Illuminance on vertical facade; Illuminance under clear or cloudy skies; Illuminance on south facing surface.

1. Introduction

The goal of daylighting for a building is to use natural light, when available from the sun, to serve the lighting needs within the building [1]. The key advantages with daylighting are two-fold – one is a decrement in electricity usage which otherwise would have been required to power artificial lighting sources and the second is the edge daylighting offers over artificial lighting from a human comfort perspective [2-5]. Therefore, assessing the potential of daylighting for a building is an important aspect of building energy studies. Artificial lighting in buildings, particularly in the commercial sector, can account for a significant portion of its electricity usage. It is reported that lighting in office buildings can account for as high as 50% of the electricity consumption, while in general, artificial lighting can use up 25 to 40% of the energy supplied to buildings [2, 6]. In the United States for example, lighting is estimated to account for 10% of the total electricity usage in the country [7]. Field survey and simulation studies estimate that using daylighting in place of artificial lighting can contribute to energy savings ranging anywhere from 20 to 70% [8-10].

Daylighting as a strategy to improve the comfort level of occupants in a building is underpinned by a number of vantages that natural light offers. For one, natural light best befits human vision through its graduated build-up and build-down during sun rise and sun set, plus, it also achieves a better color rendering score [2, 4]. Studies have established that natural lighting is more conducive to a productive and healthy working environment than is artificial lighting and cases have been made on this basis to legislate daylighting performance for buildings [11, 12]. Daylighting, on a par lighting level basis with artificial lighting, contributes less heat to the lit area which in turn can impact the cooling load generally reducing it [13]. The key however is to achieve a proper integration of the daylighting and artificial lighting systems in order to reap the benefits of a reduced electricity off take [13].

The entry of daylight into a building is typically through side fenestration like windows or through roof fenestration like skylights. In the northern hemisphere, the south facing facades of a building offer the most daylight entry and in addition, also offer the most control on ingress of direct sunlight using shading techniques [1]. The south facade is thus a top priority when considering daylighting strategies for a building located in the northern hemisphere. For most buildings, the amount of illuminance received on its vertical facades is an important daylighting design consideration and this knowledge becomes more relevant in context of an increasing adoption of features like curtain walling in modern buildings [2, 14].As part of daylighting studies for a campus building located in Canada, this paper seeks to estimate the annual range of global illuminance on a south facing vertical facade.

2. Building location and preliminary sun path study

The building under study has an orientation in the north-east direction, a site altitude of 338m and latitude and longitude references as 43^{o} 31'53.03" and 80^{o}13'34.17" respectively. A preliminary sun path study, using Autodesk's Vasari 3D sun path diagram generator, is performed in order to visualise the range within which the sun moves in reference to the building over a year. The result is presented in Figure 1. As is evident, the south facing facades present the best opportunity for daylighting.

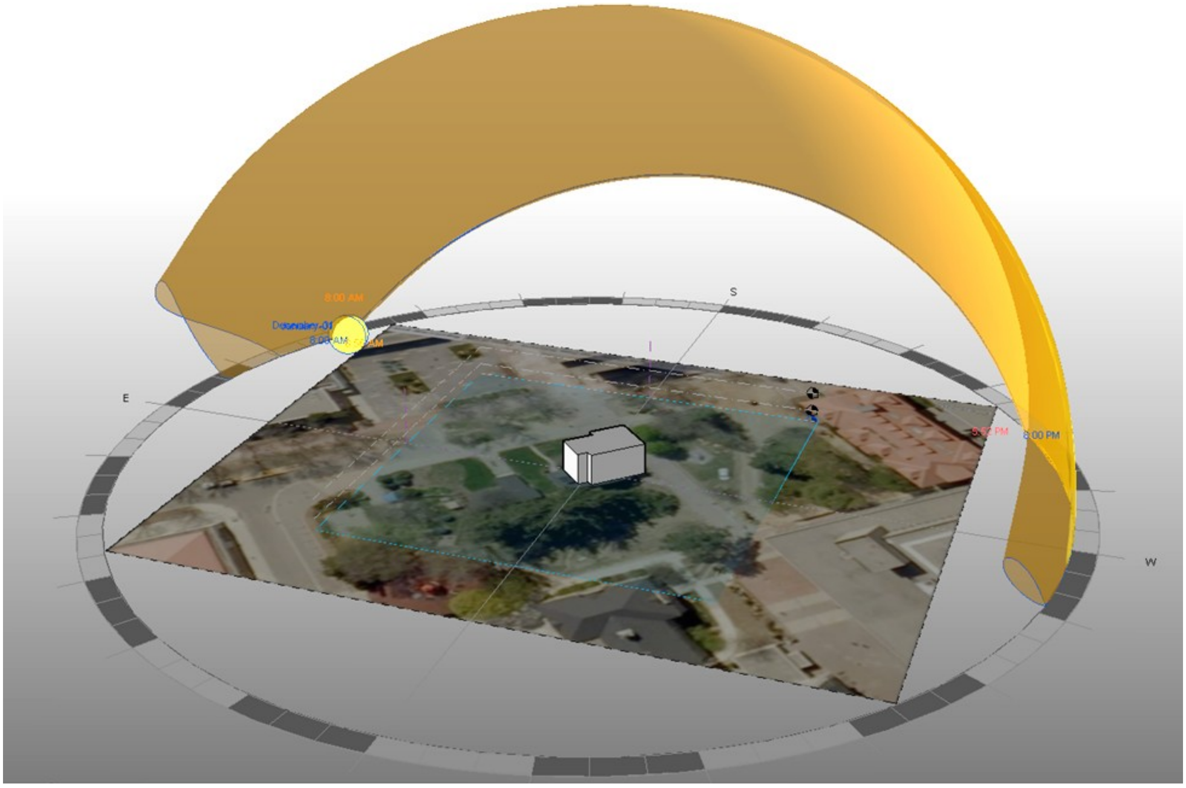

Figure 1. One year sun path study between 8am to 8pm [Courtesy – *Autodesk® Vasari*]

3. Factors influencing daylight availability at a location

When light rays from the sun reach the earth's atmosphere, close to 20% of the light is absorbed and another 25% is reflected back. [2].What is left reaches the earth partly as direct sunlight and partly as diffused light [2]. The atmosphere, which is largely made up of clouds, aerosols, water vapor and other particulate matter, is responsible for the scattering effect of sunlight which results in diffused light(skylight). In essence, the daylighting potential for a building can be contributed by sunlight, skylight or reflected sunlight or skylight from the ground surface or obstructions in proximity to the building. The amount of daylight available at a location depends on various factors. This includes, the site latitude, the site longitude, local meteorological conditions, local air quality, time of the day and time of the year and not least, characteristics of the location's immediate surroundings including the presence of nearby trees or buildings which can act as obstructions [1,2].

The apparent position of the sun with reference to any location on earth, which is one of the key factors determining the solar radiation received at a site, can be defined by two parameters – the altitude angle and the azimuth angle [8]. The solar altitude angle is the vertical angle of the sun above the horizon, while the solar azimuth angle is the angle of the sun on the horizontal from the due south. The altitude and azimuth angles can in turn be determined using the site latitude and longitude values, the solar declination angle and the solar time with the last two parameters being variables ranging between limits over a day and over a year respectively. The solar declination angle varies across seasons from +23.5 degrees during summer solstice to -23.5 degrees during winter solstice. This variation is presented in Table 1. A sun path chart for the building location, plotting the sun's elevation angle (altitude angle) and azimuth angle for different times of the day, is given in Figure 2.

Table 1. Seasonal declination angle change

Jun-22	23°27'	(Summer Solstice)
May 21/Jul 24	20°	
Apr 16/Aug 28	10°	
Mar 21/Sept 23	0°	(Autumn & Spring Equinox)
Feb 23/Oct 20	(-) 10°	
Jan 21/Nov 22	(-) 20°	
Dec-22	(-) 23°27'	(Winter Solstice)

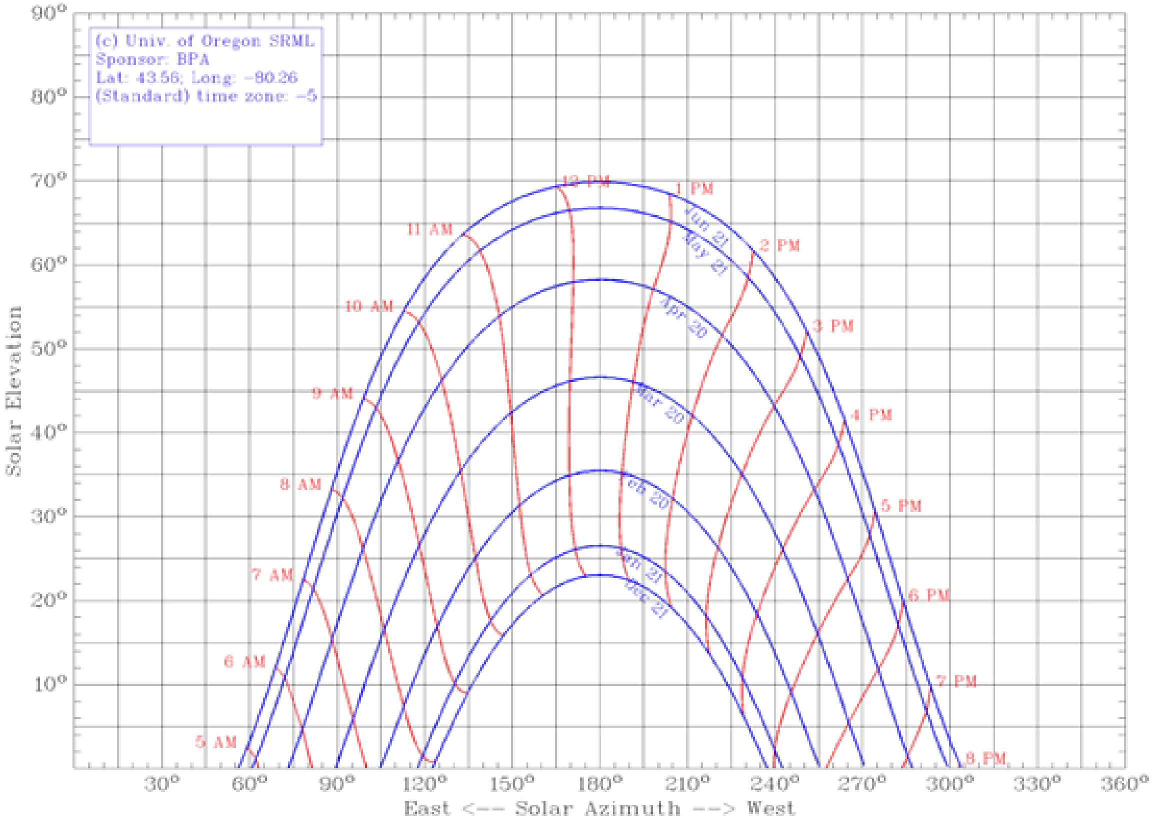

Figure 2. Sun path chart [Courtesy – *http://solardat.uoregon.edu/SunChartProgram.html*]

4. Global illuminance on a south facing vertical surface

Extensive reference is made to the IESNA Lighting Handbook [15] for the calculation methodology to be followed and the specific parameters required in estimating the illuminance for a south facing vertical surface. The relevant set of equations proposed by IESNA is presented in this section.

$$t_{solar} = t_{std} + EoT + \frac{12(M_{std} - Long)}{\pi} \quad (1)$$

where t_{solar} is the solar time in decimal hours, t_{std} is the standard time or daylight time in decimal hours, EoT is the equation of time correction applied in decimal hours considering the earth's elliptical orbit around the sun and the variable declination angle over the seasons, M_{std} is the local standard meridian reference in radians and $Long$ is the site longitude in radians.

$$\delta = 0.4093\sin\left[\frac{2\pi\,(J-81)}{368}\right] \tag{2}$$

where δ is the solar declination angle in radians and J is the Julian date ranging from 1 to 365.

$$Ang_{alt} = \arcsin\left[\sin lat\,.\sin\delta - \cos lat\,.\cos\delta\,.\cos\left(\pi t_{solar}/_{12}\right)\right] \tag{3}$$

where Ang_{alt} is the solar altitude angle in radians, and lat is the site latitude in radians.

$$E_{xt} = E_{sc}\left[1 + 0.034\cos\frac{2\pi\,(J-2)}{365}\right] \tag{4}$$

where E_{xt} is the extraterrestrial solar illuminance in KLx after correction is applied accounting for the earth's elliptical orbit and E_{sc} is the solar illumination constant which is the direct solar illuminance on a sun facing surface for a clear day and given as 128KLx.

$$Ang_{azm} = \arctan\left\{\frac{-\left[\cos\delta\,.\sin\left(\pi t_{solar}/_{12}\right)\right]}{-\left[\cos lat\,.\sin\delta + \sin lat\,.\cos\delta\,.\cos\left(\pi t_{solar}/_{12}\right)\right]}\right\} \tag{5}$$

where Ang_{azm} is the solar azimuth in radians.

$$\mathrm{m} = \frac{1}{\sin Ang_{alt}} \tag{6}$$

where m is the optical air mass with no applicable dimensional unit and which varies as a function of the angle of the sun with respect to the earth's surface [2]

$$E_{dni} = E_{xt}\,.e^{-cm} \tag{7}$$

where c is the atmospheric extinction coefficient and assigned values 0.21 for clear and 0.8 for partly cloudy sky and E_{dni} is the direct normal solar illuminance in KLx.

$$E_{dhi} = E_{dni}\,.\sin Ang_{alt} \tag{8}$$

where E_{dhi} is the direct horizontal solar illuminance in KLx.

$$E_{khi} = \mathrm{A_i} + \mathrm{B}\,sin^{C_i} Ang_{alt} \tag{9}$$

where E_{khi} is the horizontal diffuse sky illuminance due to unobstructed skylight in KLx, $\mathrm{A_i}$ is the sunrise/sunset illuminance in KLx and assigned values 0.8 for clear and 0.3 for partly cloudy sky, B is the solar altitude illumination coefficient in KLx with values 15.5 for clear and 45 for partly cloudy sky and $\mathrm{C_i}$ is solar altitude illuminance exponent with values 0.5 for clear and 1 for partly cloudy sky.

$$Ang_{z} = Ang_{azm} - Ang_{e} \tag{10}$$

where Ang_z is the solar-elevation azimuth angle measured in the horizontal place between the normal to the vertical face of study and the south in radians and Ang_e is the elevation azimuth in radians.

$$Ang_{i} = \arccos(\cos Ang_{alt}\,.\cos Ang_z) \tag{11}$$

where Ang_i is the incident angle in radians and represents the angle between the normal to the vertical surface under study and the direction to the sun.

$$E_{dvi} = E_{dni} .\cos Ang_i \tag{12}$$

where E_{dvi} is the direct vertical solar illuminance in KLx.

$$E_{kvi} = A_i + B\cos Ang_i^{C_i} \tag{13}$$

where E_{kvi} is the diffuse vertical illuminance in KLx.

$$E_{gi} = \rho_g.(E_{dhi} + E_{khi}) \tag{14}$$

where ρ_g is a ground reflectivity coefficient or albedo with a nominal value of 0.2 typically assigned and E_{gi} is the illuminance reflected off the ground in KLx.

The incident global solar radiation is then the sum of direct beam radiation, sky radiation, and the ground-reflected radiation and accordingly, the global vertical illuminance on a south facing surface is given by:

$$Ev_{south} = E_{dvi} + E_{kvi} + E_{gi} \tag{15}$$

where Ev_{south} is the total illuminance on a south facing vertical surface in KLx.

5. Results and discussion

Based on the calculation methodology proposed by IESNA, the global illuminance on a vertical south facing surface at the building location, under both cloudy and clear sky conditions, is estimated for Julian days 1 to 365. The resultant plots are presented in Figures 3 to 5.The plots show that illuminance is a variable over time, over the year and under different sky conditions. At 12 solar noon, when the illuminance is at its peak over the day, under clear sky conditions, the global illuminance value on the vertical face ranges from a low of around 65KLx to a high of around 100KLx as seen in Figure 3. On the other hand, when the sky condition is cloudy, this range drops to between 14KLx and 21KLx as observed in Figure 3. It is thus evident that the sky condition plays a significant role in determining the global illuminance value. Figures 4 and 5 depict the annual illuminance trends for solar time 9am and solar time 3pm respectively. These plots show that even for the same time of the day, over the year, as the earth revolves round the sun, the illuminance level on a vertical face varies with the range of variation as high as 35KLx. This daily and seasonal trends need to be factored in when conducting solar design studies for buildings [16, 17].

In order to ascertain the fraction of time the building location is typically exposed to overcast or clear sky cover, reference is made to the Kitchener Airport weather station cloud cover report accessed through www.weatherspark.com. This report is based on historical records from 1994 to 2012. This station is selected for its nearest proximity to the building location among available weather station records and it is within reason to assume that these records are representative of local cloud cover trends over the building. Notably as seen in Figure 6, the sky condition is observed to be overcast for close to 50% of the time during winter. As established earlier, under overcast sky conditions, the level of vertical illuminance on a surface in the south cardinal direction is relatively much lower thus emphasizing the relevance of sky condition data in support of daylighting studies.

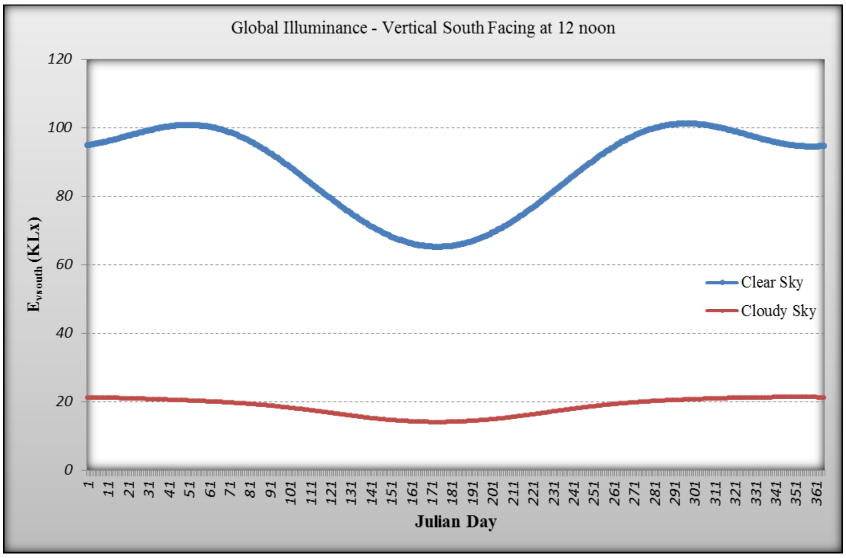

Figure 3. Global illuminance versus Julian day under clear and cloudy skies at 12noon

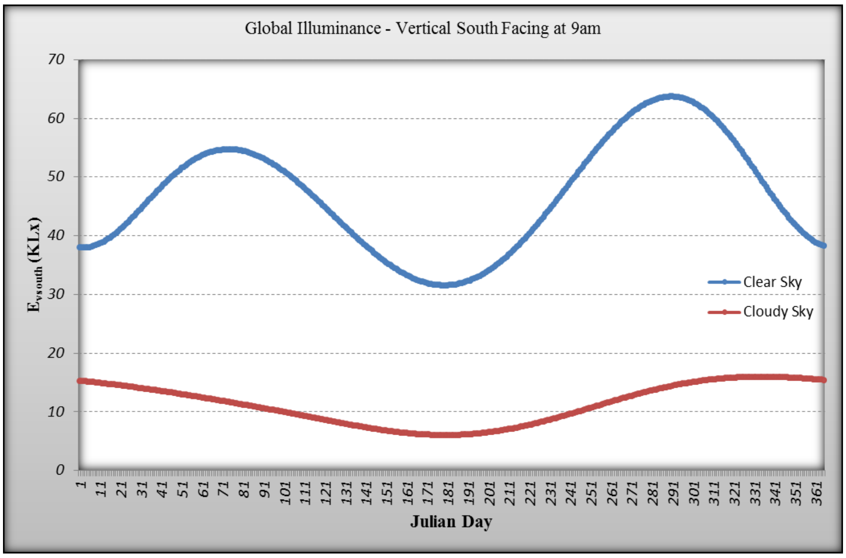

Figure 4. Global illuminance versus Julian day under clear and cloudy skies at 9am

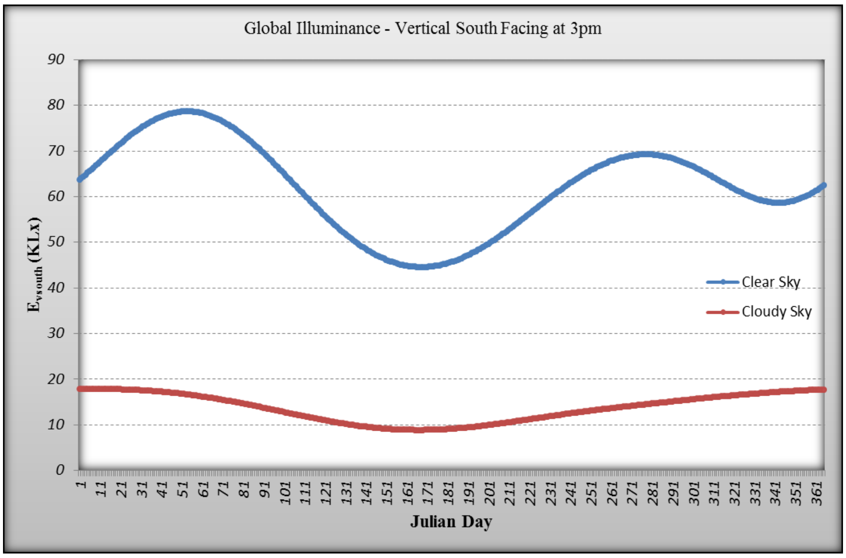

Figure 5. Global illuminance versus Julian day under clear and cloudy skies at 3pm

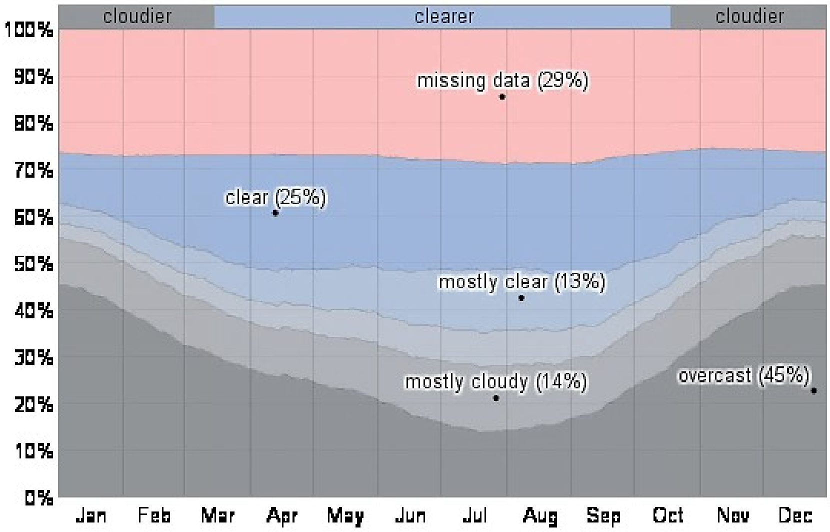

Figure 6.Cloud cover report - Waterloo region [Courtesy –*http://weatherspark.com/#!graphs;ws=28280*]

8. Conclusions

The following describes the key conclusions of this study:

- Using an IESNA defined calculation methodology, the global illuminance on a vertical south facing building surface is shown to be a variable across a day, over a year as well as under different sky conditions.
- Specific to the building location in this study, the global vertical illuminance, covering all dynamic scenarios (daily, annual and under varying sky conditions),is observed to range from a low of 14KLx to a high of 100KLx. Over the course of a day, the global vertical illuminance variation can be as high as 35KLx.
- By estimating the varying global illuminance level on building surfaces specific to a building's geographical location, and along with knowledge about the fenestration transmission properties and shading systems of the building, can aid in the creation of an effective daylighting scheme and also support feasibility studies investigating strategies such as incorporation of light transport systems.

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