Evaluating Daylighting of Glazed Atrium Spaces through Physical Scale Model Measurements under Real Tropical Skies Condition

JULITTA YUNUS[1], SABARINAH SH AHMAD[1,2], AZNI ZAIN-AHMED[3]
[1] Faculty of Architecture, Planning & Surveying,
[2] Research Management Institute,
[3] Centre of Research in Innovation and Sustainable Energy, Institute of Science,
Universiti Teknologi MARA, 40450 Shah Alam, Selangor
MALAYSIA
e-mail: [1] julitta@salam.uitm.edu.my,

Abstract: - This paper presents findings from a physical model investigation of an atrium building with four type of structured roof are shown. The experimental investigation allowed the author to evaluate daylight penetration in the atrium, while the adoption of varied modern structured roof constructions for the atrium allows one to obtain an insight into their effect upon the variation on daylight distribution patterns in terms of Daylight Ratio on horizontal surface. Intermediate skies revealed a complex pattern on daylight performance in the atrium attached by varied roof structure. From the results, it is clearly shown that, a high contribution of daylight penetration appears at the centre nearest to the atrium opening, while the transmittance of the atrium roof structure decreased the illuminance level at the corner by 50%. The flat roof has the highest daylight illumination for both skies condition The study also found that, under overcast skies, critical attention should be made to the corner location of the atrium especially for north- and west-facing atrium surfaces as the illuminances greatly decreased for all type of roofs. The atrium roof shapes and their structure systems, orientations to the sun and skies conditions are important parameters in the daylighting design of atrium buildings. The types of sky conditions in different climate region begin more significant parameters to be included when determining the daylight performance for the atrium building.

Key-Words: - Daylighting, Atrium, Physical Model Measurements, Illuminance, Daylight Ratio, Tropical Skies

1 Introduction

The glazed atrium is a relatively popular in recent development. This design trend are recognized as one of the most popular and environmentally stimulating spaces of today's architecture [1, 2]. Atrium, where a space attached to a large building or placed between two or more such buildings, can provide parent building with daylight, natural ventilation, if south-facing, useful passive solar gains, which all of these functions are potentially energy saving. The key factor is daylight, where the role of roof is major: a careful design of the roof fenestration systems limits glare, mitigates passive solar heating effects and supplies adequate daylighting and minimum sun-lighting.

The atrium indoor environment problems mainly caused by the large areas of glazing and large volume of the space. However, they are designed to allow visual openness and natural lighting which then may also allow excessive solar gain, particularly in tropical countries. So how to make this natural benefits of the traditional open space are not lost with its glazing. Several studies [3-5] suggested that daylighting implementation in tropical buildings could optimize the lighting ambience and reduces glare comfort, which can be achieve through top-lit and side-lit apertures. However, to achieve optimum daylight performance, it is necessary to have a good understanding of how daylight is transmitted into a space.

The uniqueness of Malaysia that falls under tropical climates is their sky. The Malaysia sky type has been identified as intermediate sky (i.e. average cloudy condition with cloud cover value of 6-7 oktas) [6, 7]. Moreover, the Malaysian daylight design criteria are within 10-80klux during working hours 8am to 5pm. This suggests that the possibility to implement daylighting in buildings in Malaysia is very high. Therefore, despite the potential of having full use of skylight alone (diffuse light from the sky, excluding sunlight), large glazing areas adapted literally from international style designs were unacceptable which regards to Malaysia's high sky irradiance factor that contributed to visual discomfort and higher cooling load. The daylight 'rule-of-thumb' and innovative technique were already established and recommended to cater this, however it was not considered a mayor topic until recently. In fact, Malaysia buildings are behaving lack of apprehension especially at the era between early 1960s until the 1990s, where building were erected without any reference or adaptation to local climate [8-10].

For countries close to the equator, like Malaysia because the sun shines straight overhead in the afternoon most of the year with noon sun angles of 66.5^0 (June solstice) to 113.5^0 (December solstice). Due to this condition, the daylight prediction techniques were complicated. Despite several arguments on these prediction method, [11-13], namely daylight factor, daylight coefficient, illuminance ratio, it was then expressed that a commonly used daylight factor cannot account for non-overcast sky luminance patterns or the sun So it is more accurate to use the daylight ratio to obtain the percentage ratio of internal illumination level with its simultaneous external illumination level, which can be taken as a constant [9, 13]. This constant ratio is expressed as a percentage as shown in Equation 1.

$$\text{Daylight Ratio} = \frac{\text{Internal illumination}}{\text{External illumination}} \text{ X } 100 \qquad \text{.........Equation 1}$$

Physical scale model experiment has been used as the method of investigation since it assesses luminance levels under real sky conditions (i.e. intermediate sky). This reliable method provides incisively quantitative and qualitative results to support decision-making process on daylight performance for buildings. Besides, scale models are useful because light does not require any scaling corrections. Judging from current most frequent built atrium skylights [10], this experiment had considered various roof shapes and form including their roof truss system to be modeled as for more accurate and meaningful results. This is due to the initial investigation [14] had revealed real-time evidence on the measured effects of roof obstructions upon daylight levels in atria under real sky conditions using physical scale models. Results showed intermediate skies revealed a generally linear relationship and had a good degree of correlation with the overall reduction of daylight levels. Internal obstructions tend to reduce about 55% of light transmittance with similar pattern of losses for all roof profiles. It was observed that the internal obstructions of roof created relatively constant attenuation of the daylight compared with the clear unobstructed roof. In search of the deeper understanding on the effects of atrium roof forms and internal structural obstructions (roof truss) upon the daylight levels in atrium buildings under tropical real sky conditions, this experiment study had further analyzed and evaluated the daylight performance in atrium spaces that have resulted by incorporating the roof truss system.

2 Methodology

2.1 The Physical Scale Model under Real Sky Conditions

A 1:50 scaled model was used to investigate the daylight distribution and illuminance level of an atrium building with different roof fenestration designs (Fig.1a). The model was scaled to 1:50 as it is the most appropriate size [15] to simulate a square four-sided top-lit atrium. Its full-scale dimensions were $400m^2$, with four floors of 3.0 m height each and measured for sun and skylight distributions under real sky conditions. The model (Fig. 1b) was made of 12mm thick MDF board, with internal size of 400mm x 400mm x 240mm, with a Plan Aspect Ratio (PAR) of 2, a Section Aspect Ratio (SAR) of 2 and Well Index (WI) of 1.0. The internal sides of the model were painted matt black to minimize internal surface reflections (about 2%) to focus on roof transmittance. The external walls were painted with white gloss to maximize external surface reflectance (about 85%). The model was tested under real sky conditions in Shah Alam, Selangor, Malaysia, located at Universiti Teknologi MARA, with latitude longitude of 3^o 101^o. Since the model was solely top-lit, it was placed on 1.5m high platform, at the roof-top of a 4-storey building, to avoid obstruction from surrounding area (Fig. 1c).

Four types of roof forms were used in the investigation: a) structured flat roof, b) Structured Pyramidal-Gridded Roof, (roof height 60mm, pitch angle 180), c) Structured north-south facing Saw-tooth Roof and d) structured west-east sloping glazed Pitched roof (roof height 165mm, pitch angle 180). All roofs were constructed with 2mm thick clear glazing and white-painted wooden struts that represent roof trusses

ISBN: 978-1-61804-001-5

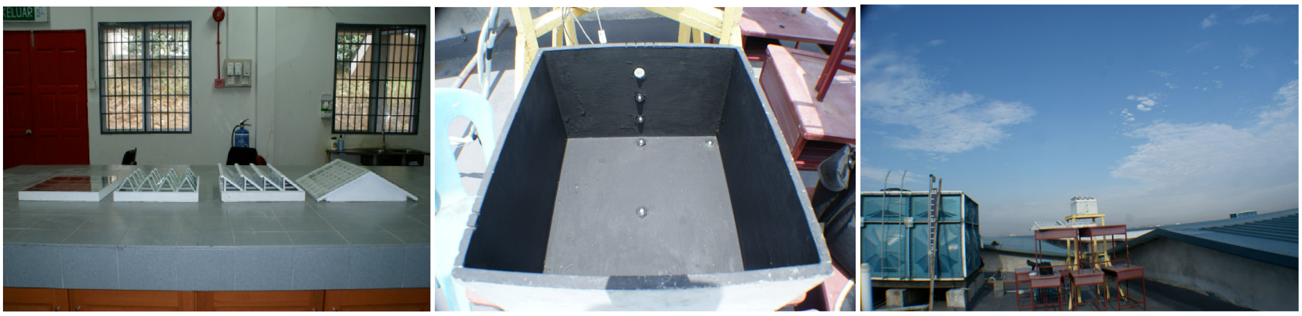


Figure 1. Physical scale model experiment (from left to right) a)Four types of roof systems, b)atrium model painted matt black c)experiment at rooftop

2.2 The Equipment Set-up and Illuminance Measurement

The physical scale model was equipped with six newly calibrated illuminance sensors EKO Luxmeter (ML020O) for outdoor illuminance monitoring under real sky conditions. Horizontal measurements were made on the atria floor (centre, corner and central edge positions). Vertical measurements were taken from three sensors positioned on the central line of walls with heights of 60mm, 120mm and 180mm above the floor level (Fig. 2a). All measurements were kept constant by drilling 22mm diameter holes for six sensors, and the top surfaces of the sensors were pushed through the hole so that the sensors' surface were flushed with the wall. Thus, 16 illuminance measurements were made in each model for each roof profile per half hour.

All internal illuminance measurements were set for the various combinations of roof type, sky type, four-ordinance orientation and position of sensors in each model. The illuminance sensors were attached to independent data logger (dataTaker DT80) for all internal measurements. Three sensors were positioned horizontally and another three vertically (Fig. 2b). The sensors were connected to six individual channels that gave outputs corresponding to a range of illuminances for each individual luxmeter. Some of the channels had to be modified to measure to over 130,000 lux. A data logger, connected to a portable computer, recorded the illumination level of each sensor using a computer program called DeLogger5. Extech Illuminance Meter (HD450) with built-in memory was used for external illuminance measurements that ran simultaneously with the internal illuminance measurements. Illumination levels were logged five times per minute, repeated for four-ordinance orientation for each type of roof, with 15 minutes interval, between 8.00am and 6.00pm under real sky conditions.

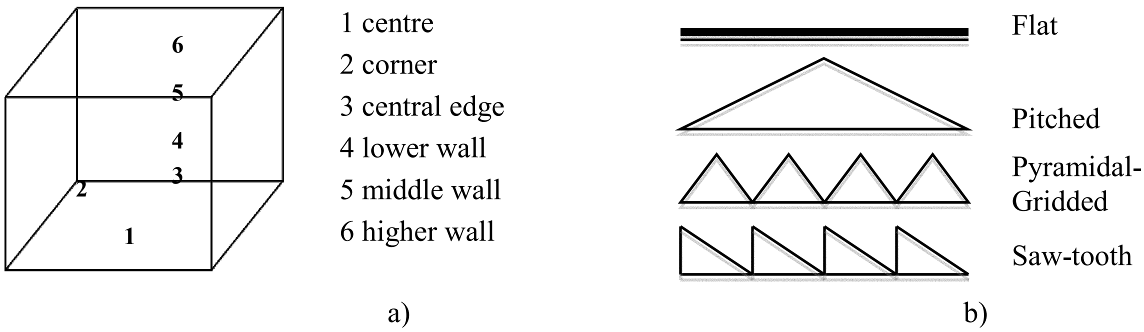


Figure 2. Illuminance Measurement. a) Sensors location (b) Roof profile model

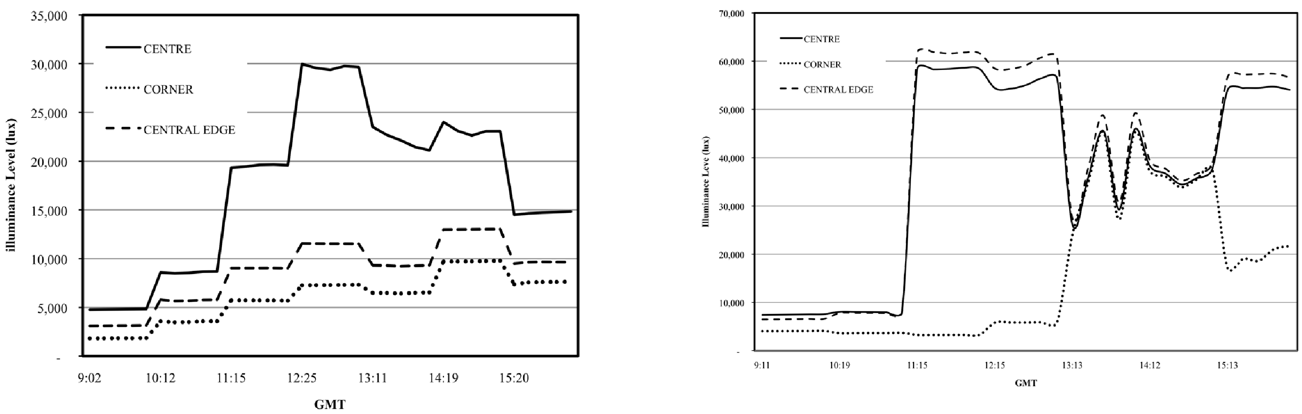
3 Results

Results from the measurements were quantified based on distribution of light within the atrium interior including average illumination, variance within daylight hours and minimum and maximum illumination. Then these datasets were analyzed two ways:

- External and internal horizontal illumination to derive the pattern of daylight transmittance for atrium floor level over the daylight hours for each atrium roof configuration.
- The effects of roof profiles upon daylight transmittance at atrium floor level by calculating measured data using formula in Equation 1.

3.1 External and Internal Horizontal Illumination Analysis

External and internal horizontal illumination data were used to estimate daylight ratios available in the atrium measured. First of all, from the results, generally it is apparent that illuminance levels are more constant during the overcast day, while there are sharp illuminances gradient at some positions (i.e. corner and central edge) on the sunny day. This is showed in the Figure 3a and 3b below (example of flat roof). Secondly, for all four types of roof are, on both days, the centre positions is measured with the highest illuminance level, with average of 21 Klux on sunny days and 14Klux on overcast day. Meanwhile the lowest illuminance level is at the corner position with average of 10Klux on sunny day and 7 Klux on overcast day. And for the central edge position is receiving 75% of illuminance level that reached the centre position of atrium floor. Figure 3 shows the average internal illumination level at the centre, corner and edge positions for four types of roof with uniform reflectance of 0.02% for two different types of sky condition. It is evidence that the flat roof was observed to have the highest illuminance for both skies condition whenever there is the highest external illuminance level occurred. While the other three roofs, it was recorded that despite the relatively low external illumination level, the central edge were received a high amount of illumination transmittance (Table 1).



(a) (b)

Figure 3. Illuminance Level at Atrium Floor for Flat Roof under real sky conditions for both days, a)Overcast Day b)Sunny Day

Table 1. Internal illumination and external illumination level at centre, central edge and corner positions on the floor for four types of roof with uniform reflectance of 0.02% measured on overcast day.

Roof Type	Position	Internal Illumination, lux			External Illumination, lux
		Centre	Central Edge	Corner	
Flat	N	19,208	9,223	6,416	66,619
	W	18,058	15,400	7,189	63,689
	S	21,671	21,376	16,313	69,859
	E	**23,342**	12,692	10,701	**72,040**
Pitched	N	**18,015**	8,205	5,790	65,036
	W	15,369	12,423	6,243	65,413
	S	17,512	17,189	11,465	**68,576**
	E	17,193	9,549	8,366	67,571
Pyramidal-Gridded	N	15,543	8,033	5,622	64,094
	W	18,347	16,077	6,376	68,494
	S	17,716	**19,052**	13,684	**70,904**
	E	16,128	8,770	7,682	69,080
Saw-tooth	N	1,788	**2,247**	1,688	61,917
	W	1,850	1,502	1,784	69,930
	S	1,878	1,054	1,373	**72,590**
	E	1,863	1,488	811	72,474

3.2 Daylight Ratio Analysis

Using Equation 1, daylight ratio for atrium spaces were determined for all types of roof. Figure 4 and 5 below shows the daylight ratio calculated different locations of atrium floor level for four types of roof under real sky conditions. It was observed that, for all type of roof under overcast sky condition, the daylight ratio decreased constantly according to measurement location, with centre is the highest, followed by central edge and corner as the lowest. Meanwhile, under sunny day, the ratios varies very minimum between the measurements locations for all type of roof.

For the daylight ratio patterns, it can be observed that under overcast day, centre position received the highest amount with average of 20% while corner is decreased more than half of the amount with average of 8%. Flat roof is measured to have the highest daylight ratio with average of 19% followed closely by Pitched and pyramidal-gridded roof with ratios of 16% and 15% respectively. The scenarios of constant clouds pattern and movement could have been contributing to more stable results. On the other hand, the decreasingly patterns between the measurement locations were very minimum under sunny days, ratios different only o% - 2% between measurements location. However, there is relatively high different of daylight ratios received by the roof type. The flat roof was measured of 32%, then pyramidal-gridded roof with 28%, followed by pitched roof where the ratios decreased to 20%. This conditions could have been influence by the present of internal structure system for each type of roof, where there are evidence [14] that those internal roof structure system and inclination of glazed roof could have been reflecting the bright sunlight away or into the atrium more when the sky brightened.

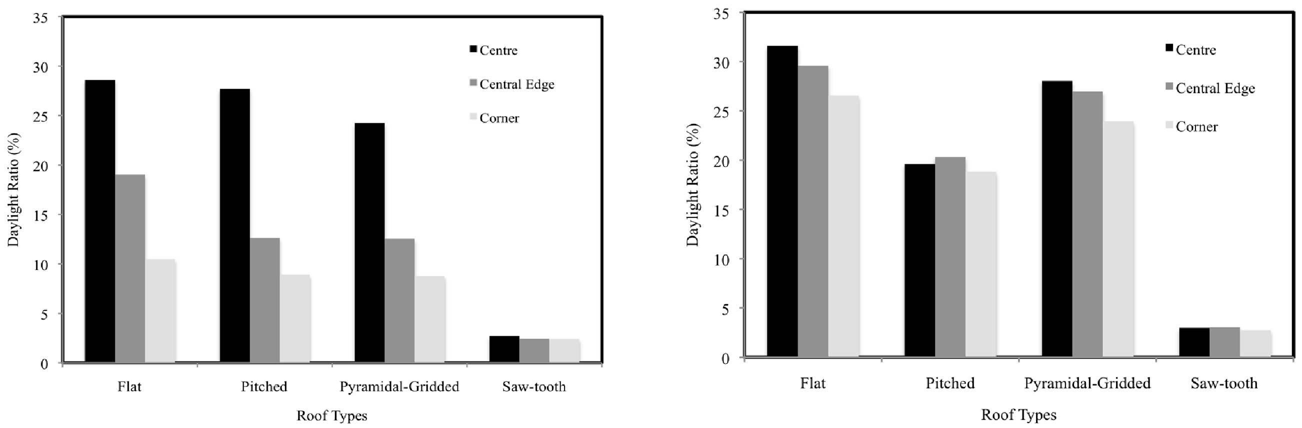


Figure 4. Daylight Ratio at atrium floor level for overcast skies (left) and sunny skies (right)

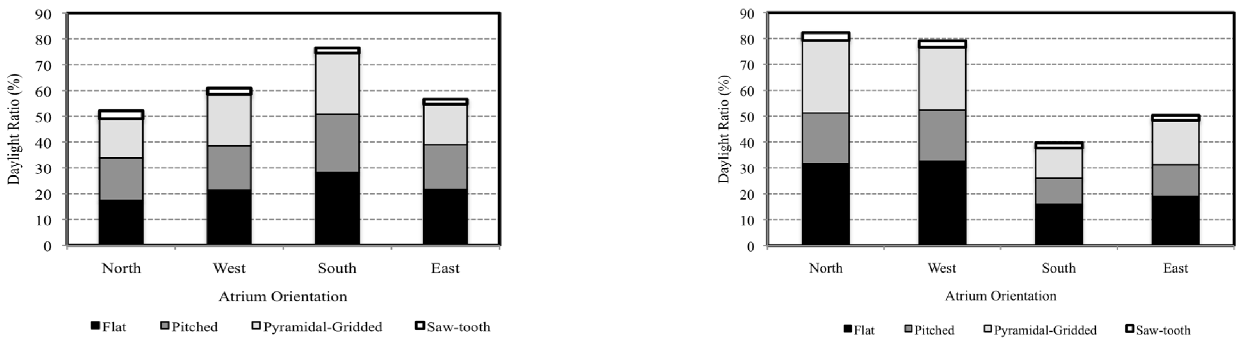


Figure 6. Daylight Ratio at different orientation under overcast skies (left) and sunny skies (right)

In order to understand the behavior of daylighting for atrium spaces, the orientation factor were added into complication of measurements. It is interesting to note that under overcast sky condition, the south- and east facing are exposed to the highest daylight ratio, despite their relatively low external illumination level. Conversely, under sunny day, the north- and west- facing atrium received the highest daylight ratio. This results has a good agreements with the results showed both measured in temperate and tropical climates [9, 16]. This shows that, despite different types of roof, orientation and sky conditions has a clear influence over the daylight level of an atrium space.

4 Conclusion

This investigation was put an attempt to have only one parameter, i.e. roof transmittance, which is why the atrium surfaces were painted in black. Further computer simulation works will be executed in order to examine others importance factors such as interactions between surface reflectance, daylight levels, atrium well index and different time of a year. This study has concluded the following:

- Flat roof has the highest daylight illumination for both skies condition
- At floor level, centre position received the highest illumination, followed by central edge (75%) and corner is the lowest with only received 50% of light transmittances (overcast skies)
- Under sunny skies, the effects of roof structure and the pattern of roof transmittance are more complicated than a overcast skies
- The types of sky conditions in different climate region begin more significant parameters to be included when determining the daylight performance for the atrium building.

5 Conclusion

This study was funded by the e-Science Fund from the Ministry of Science, Technology and Innovation, Malaysia.

References:

1. *Sharples, S. and D. Lash, Daylight in Atrium Buildings: A Critical Review. Architectural Science Review, 2007.* ***50.4****: p. 301-312.*
2. *Hung, W.Y. and W.K. Chow, A Review on Architectural Aspects of Atrium Buildings. Architectural Science Review, 2001.* ***44****(3): p. 285-296.*
3. *Chirarattananon, S., P. Chaiwiwatworakul, and S. Patanasethanom, Challenges of Daylighting with the Luminosity and Variability of the Tropical Skies. Lighting Research and Technology, 2003.* ***35****(1): p. 3-10.*
4. *Kischkoweit-Lopin, M., An Overview of Daylighting Systems. Solar Energy, 2002.* ***73****(2): p. 77-82.*
5. *Zain-Ahmed, A., et al., Daylighting as a Passive Solar Design Strategy in Tropical Buildings: A Case Study of Malaysia. Energy Conversion & Management, 2002.* ***43****(2002): p. 1725-1736.*
6. *Zain-Ahmed, A., Daylighting and Shading for Thermal Comfort in Malaysia Buildings, in Department of Engineering. 2000, University of Hertfordshire.*
7. *Shahriar, A.N.M. and M.A. Mohit, Frequency Distribution of CIE Standard General Skies for Subang, Malaysia. Architectural Science Review, 2006.* ***49****(4): p. 363-366.*
8. *Ahmad, M.M.R.M., Design Principles of Atrium Buildings for the Tropics. 2000, Johor: Universiti Teknologi Malaysia.*
9. *Dahlan, N.D., et al., Daylight Ratio, Luminance and Visual Comfort Assessment in Typical Malaysian Hostels. Indoor and Built Environment, 2009.* ***18****(4): p. 319-335.*
10. *Yunus, J., S.S. Ahmad, and A. Zain-Ahmed. Analysis of Atrium's Architectural Aspects in Office Building under Tropical Sky Conditions. in International Conference In Social and Science Research. 2010. Kuala Lumpur.*
11. *Kittler, R., Daylight Prediction and Assessment: Theory and Design Practice. Architectural Science Review, 2007.* ***50.2****: p. 94-95.*
12. *Li, D.H.W., C. G H W, and K.L. Cheung, Evaluation of Simplified Procedure for Indoor Daylight Illuminance determination against Data in Scale Model Measurements. Indoor and Built Environment, 2006.* ***15****(3): p. 213-223.*
13. *Mardaljevic, J., The BRE-IDMP dataset: A New Benchmark for the Validation of Illuminance Prediction Techniques. Lighting Research and Technology, 2001.* ***33****(2): p. 117-136.*
14. *Yunus, J., S.S. Ahmad, and A. Zain-Ahmed. Analysing the Impact of Roof Obstruction on Daylight Levels in Atrium Buildings: Physical Scale Model under Real Sky Conditions. in 2nd International Conference in Environmental Science and Technology. 2011. Singapore.*
15. *Thanachareonkit, A., Comparing Physical and Virtual Methods for Daylight Performance Modelling Including Complex Fenestration Systems, in Solar Energy and Building Physics Laboratory (LESO-PB). 2008, Ecole Polytechnique Federale de Lausanne: Lausanne, Switzerland. p. 241.*
16. *Sharples, S., and Shea, A D, Daylight Transmission of Atrium Roofs Under Overcast and Partly Cloudy Skies. Lighting Research and Technology, 2000.* ***32****(3): p. 153-155.*