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A Method to Calibrate Daylight Factor at Enclosed Internal Corridor Using Scaled Model and Simulation

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Abstract: *Enclosed corridors are long, and they usually have no window provisions and require electric lighting to be switched on for 24 hours continuously to operate. Some corridor designs have openings for daylight at the ends, while others supplement daylight at the middle. The most part of these corridors are dark and consuming a lot of nonrenewable energy from artificial light. This paper explores how enclosed internal corridors do get the benefits of daylight depending on the corridor designs. It explores how %DF (Daylight Factor) less than 1%, especially in Malaysia where the skies are bright, can be beneficial and useful. The illumination required for corridors are minimal according to standards. Field work measurements were taken in selected enclosed corridor of a hostel building on typical overcast days and readings on %DF were then recorded. A scaled model of similar design was built to be experimented in the artificial sky to get a same set of readings; followed by simulation using Radiance. Results show that the readings calibrate well between field work compared to the scaled model in artificial sky and simulation with less than 10% differences. It was found that values of % DF of 0.5 and below calibrated well. Comparison were also carried out in terms of absolute illuminance and it was found that daylight illuminance less than 40 lux in corridors should not be underestimated and were still useful even though lower than the usual standards for corridor illumination. This successful calibration will be used for further experimentation how enclosed corridors can be naturally lit by simulations.*

Keywords: Daylighting, Daylight Factor, Energy Saving, Corridors Design

1. Introduction

Corridor is a narrow passageway or gallery connecting parts of building (Ching, 2012). A corridor often has entry points to rooms located adjacent its path. However, interior corridors are usually provided with artificial lighting 24 hours a day (Hansen, 2006). Therefore, this leads to the consequence of huge increase in energy consumption which has several direct and indirect harmful effects (i.e., unhealthy and infertile environments, non energy-efficiency, production of greenhouse gases and use of nonrenewable resources for the occupants of the building. Due to the rising demand in energy utilization and need for energy-saving, daylighting has been considered as a key element in buildings' design and construction. A major challenge for architect/designer is to provide sufficient natural lighting into deep spaces of buildings. The main concern is how to bring daylight into the deep areas of office buildings to improve visual comfort of office workers in workplace conditions and also improve energy efficiency in indoor corridor spaces. Energy consumption by electric lighting system can be significantly reduced if daylighting is properly designed and integrated. As stated by a study conducted by the International Energy Agency (2016), lighting accounts for about 19% of the total energy consumption all around the world (Akrasakis & Tsikalakis, 2018; International Energy Agency, 2016).

The energy used for lighting can be reduced by lessening the usage of indoor artificial lighting and optimize daylighting instead. One of the strategies used to optimize daylighting is the borrowed daylight technique. Borrowed daylight technique is mainly related to the illumination of an enclosed internal space using a window connected to an adjacent space with direct natural lighting. However, less amount of daylight is provided into the internal space using this technique, a connection with the outside can be provided by the borrowed daylight technique. Besides, this technique can be useful when the required lighting the internal space is lower than in the adjacent room with daylight such as corridors. Therefore, the purpose of this paper is to examine how lighting internal corridors can be achieved by the borrowed daylight technique. However, to achieve the objective of the paper, a method using the Daylight Factor has been used to calibrate between field work to scale model and simulation method. It is applied specifically in enclosed corridor design in topic.

2. Daylighting

Natural lighting is perceived to have significant advantages on people and the indoor environment. These advantages include significant savings in the cost of energy used, as well as improving the indoor visual comfort. Moreover, it is described as the optimal lighting source as daylight is considered as the best sources of light that has good colour rendering and closely matches the visual response of human eye (Li & Tsang, 2008). As daylight transmitted to space, a pleasant atmosphere is created while a connection with the outside environment is maintained. people prefer and anticipate good daylight in their working or staying environment (Roche et al., 2000). The benefits of daylighting are far-reaching, as the following schematic illustrates in Figure 1.

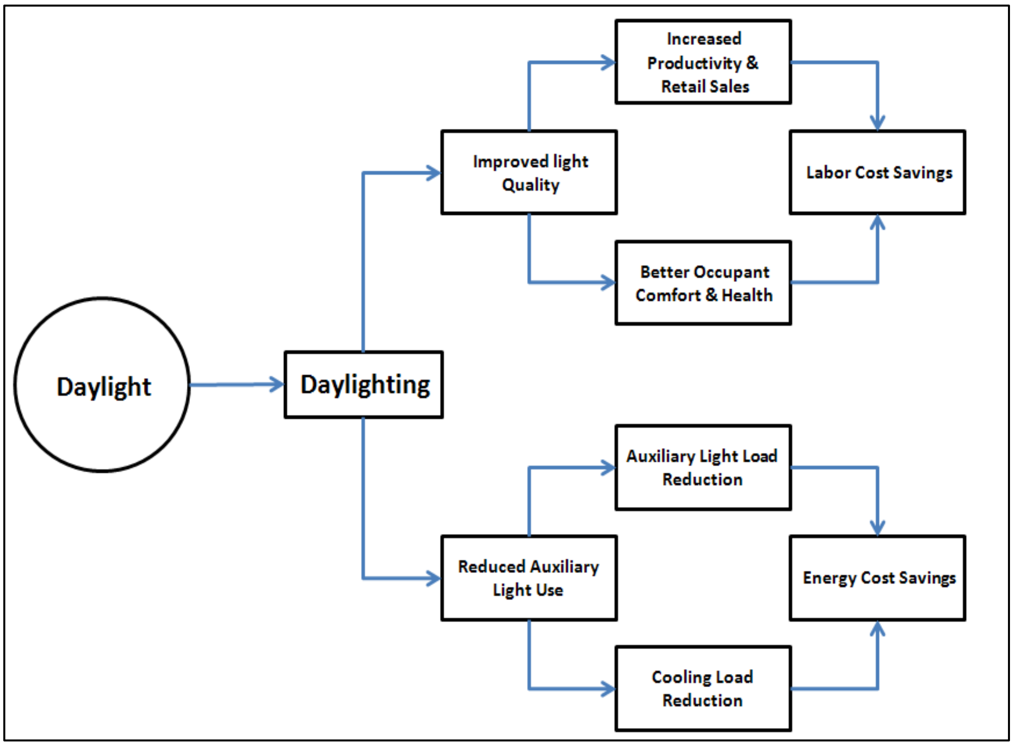

Figure 1: Benefits of daylighting (Boyce et al., 2003)

In addition, the human eye is much adaptable low level of daylight which cannot be method with similarly low levels of artificial sky. That is why daylight even in low levels should be enough in corridors where task illuminance is at min level.

Until the late 1990s, the lighting requirements for good vision was the main concern when lighting guidelines and recommendations were placed. Recently, a comprehensive definition of lighting quality including architectural aspects, human needs, and economic provisions has been adopted by the lighting community, as illustrated on Figure 2.

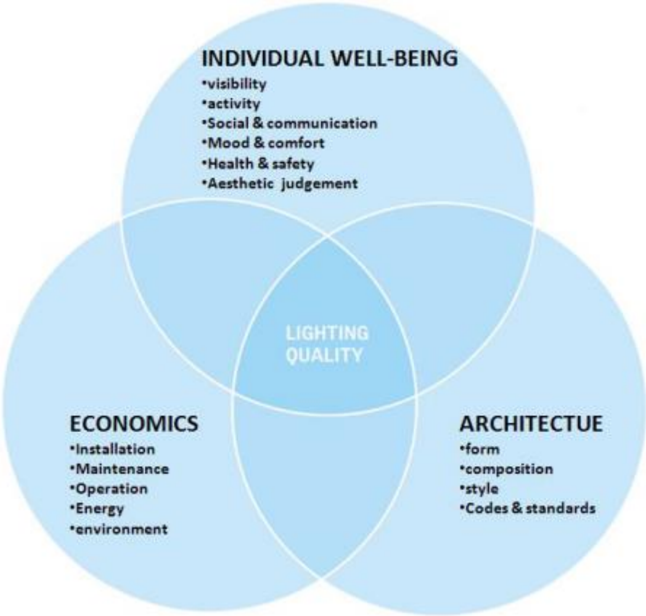

Figure 2: Daylighting quality (Veitch et al., 1998)

3. The Malaysian Sky

The type of sky in Malaysia is not easily characterised by the standard classifications of sky condition. The sky condition can be variable and inconsistent over the course of a day. This is due to the formation of cloud which constantly move across the sky. When the cloud is very thick, the sun can be totally hidden, and these conditions result in an overcast sky which usually occurs during the monsoon season and in the early morning. Where the clouds are frequently moving, the sunlight penetrates through the thin layer and makes the sky bright with intense daylight around the edges of cloud. Partly cloudy and cloudy skies are also quite common when the moisture content of the air is very high. This commonly occurs when it is about to rain or before the unpredictable rainy spells throughout a typical day. The type of sky in Malaysia recommended the use of an 'intermediate sky' by using the solar radiation data accumulated for 21 years from the Malaysian meteorological station. (Shahriar & Mohit, 2006; Zain-Ahmed, 2000). Figure 3 shows that December, June and March are the critical months for daylight in Malaysia in which illumination level can reach about 60,000 1ux, 70,000 1ux and 80,000 1ux respectively (Zain-Ahmed, 2000).

The enclosed indoor corridor design normally has minimal openings for daylight therefore % DF in corridors can be anticipated minimal indeed. The objective of the paper is to calibrate the minimum %DF in field work to scale model and simulation.

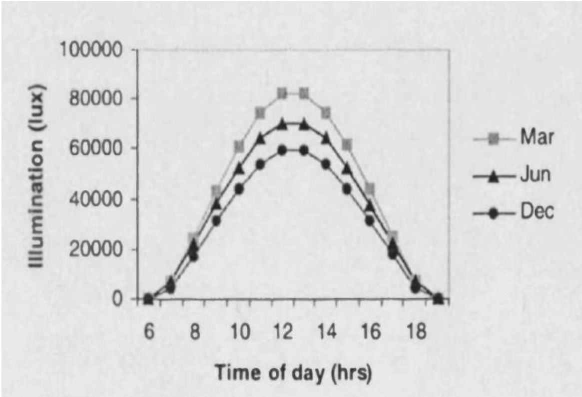

Figure 3: The illumination of daylight at critical months in Malaysia (Zain-Ahmed, 2000)

4. Methodology

The research methodology used is experimental method. Experiments were conducted at University of Science Malaysia (USM) Environmental laboratory the artificial sky. Field measurement carried out for validation of research. The scale physical model was structured to be tested under artificial sky condition. The same model was designed in the Radiance software to performing daylighting simulation experiments as shown in Figure 4.

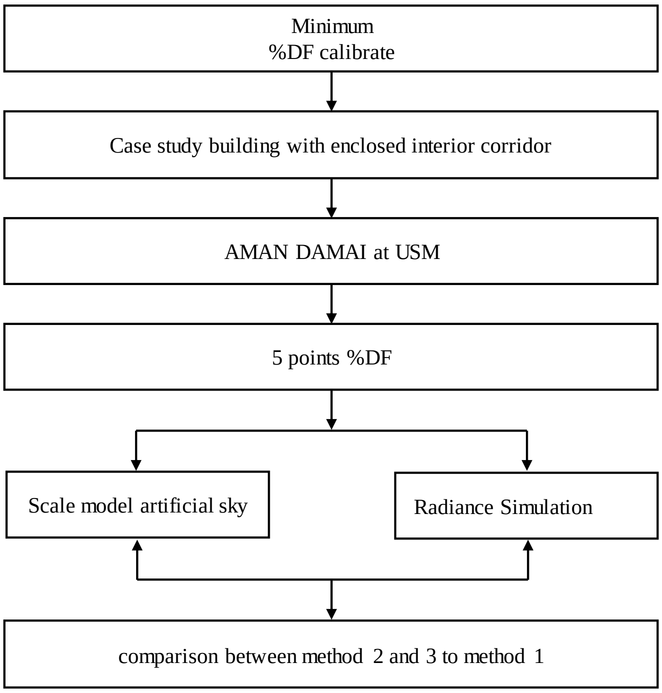

Figure 4: Research flowchart

4.1 Field work case study

The case study for corridor was in AMAN DAMAI residential building, located in the University Science Malaysia. The building consists of 3 floors, each floor of the building consists of 24 rooms, 2 bathrooms and 2 washrooms. The corridor is 1.50-meter width x 72.20meter length as shown in Figure 5.

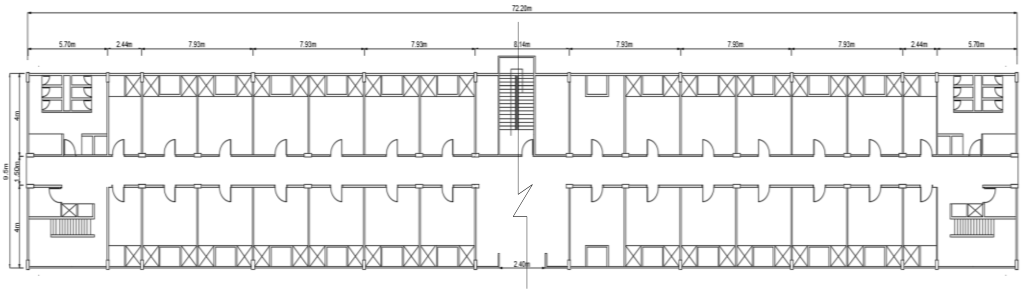

Figure 5: Floor plan of AMAN DAMAI building.

Because the building is very long, we just simplify to half of building to use in this study. Measurements were carried out in (Dec 6, 2019). The illuminance levels were measured by lux meter (LM-8100) at 5 specific points on the chairs' surfaces (0.75 meter) as shown in Figure 6. The reading was taken from 10:00 am to 4:00 pm every 30 minutes. The calculation of daylight factor was achieved by simultaneously recording the outdoor illumination level and the indoor illumination level.

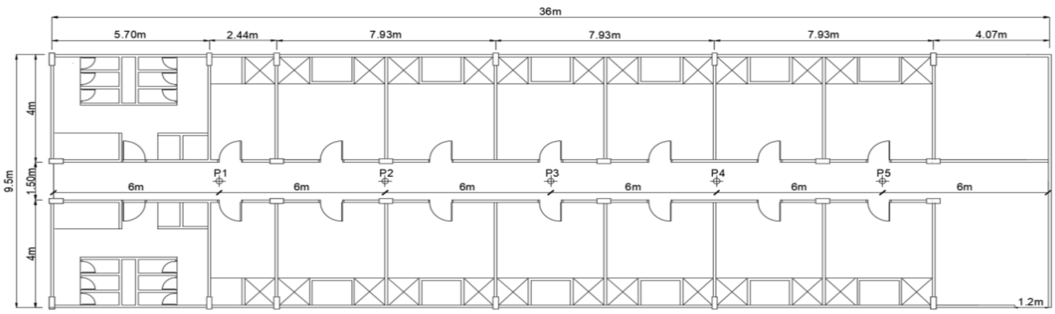

Figure 6: Photo of half of the AMAN DAMAI building.

Table 1: Average of illumination values for field work

Time	Point 1	Point 2	Point 3	Point 4	Point 5	E0
10:00 am	32 Lux	2 Lux	1 Lux	2 Lux	32 Lux	8.000 Lux
10:30 am	35 Lux	2 Lux	1 Lux	2 Lux	35 Lux	10.000 Lux
11:00 am	36 Lux	2.75 Lux	1.2 Lux	2.75 Lux	30 Lux	20.000 Lux
11:30 am	39 Lux	2 Lux	1.5 Lux	2 Lux	30 Lux	25.0000 Lux
12:00 pm	50 Lux	3 Lux	2 Lux	3 Lux	40 Lux	35.000 Lux
12:30 pm	55 Lux	4 Lux	3 Lux	4 Lux	40 Lux	40.000 Lux
1:00 pm	48 Lux	4 Lux	2.5 Lux	4 Lux	40 Lux	40.000 Lux
1:30 pm	45 Lux	5 Lux	2 Lux	5 Lux	45 Lux	40.000 Lux
2:00 pm	43 Lux	3 Lux	1.3 Lux	3 Lux	41 Lux	35.000 Lux
2:30 pm	40 Lux	2 Lux	1 Lux	2 Lux	40 Lux	26.000 Lux
3:00 pm	39 Lux	2 Lux	1 Lux	2 Lux	30 Lux	25.000 Lux
3:30 pm	36 Lux	2 Lux	1 Lux	2 Lux	30 Lux	20.000 Lux
4:00 pm	22 Lux	2 Lux	1 Lux	2 Lux	22 Lux	10.000 Lux
Average	40 Lux	2.75 Lux	1.5 Lux	2.75 Lux	35 Lux	25.000 Lux

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4.2 Scale model study

Experiments are conducted at University of Science Malaysia (USM) Environmental laboratory the artificial sky. A physical scale model constructed at a scale of 0:75 for lighting tests. It is built using thick white cardboard paper sheet covered with black sheet to avoid light leakage. as shown in Figure 7.

Figure 7: Scale model under artificial sky.

Table 2: Average of illumination values for artificial sky.

Point 1	Point 2	Point 3	Point 4	Point 5	E0
24 Lux	1.6 Lux	1.04 Lux	1.6 Lux	20.8 Lux	16.000 Lux

4.3 Radiance Simulation study

In the 3rd method, the radiance software was selected to assess the lighting design of a similar corridor. The US Department of Energy developed Radiance software that uses highly accurate ray-tracing system for UNIX computers. Many studies reported that daylight simulation methods using Radiance dynamic approach can accurately and efficiently simulate complicated daylighting elements such as Venetian blind system and the use of different shading strategies (Mardaljevic, 1995; Reinhart & Walkenhorst, 2001). The local weather data file was used for Radiance calculations for a specific moment. The same model was designed in the Radiance software to perform daylighting simulation experiments as shown in Figure 8.

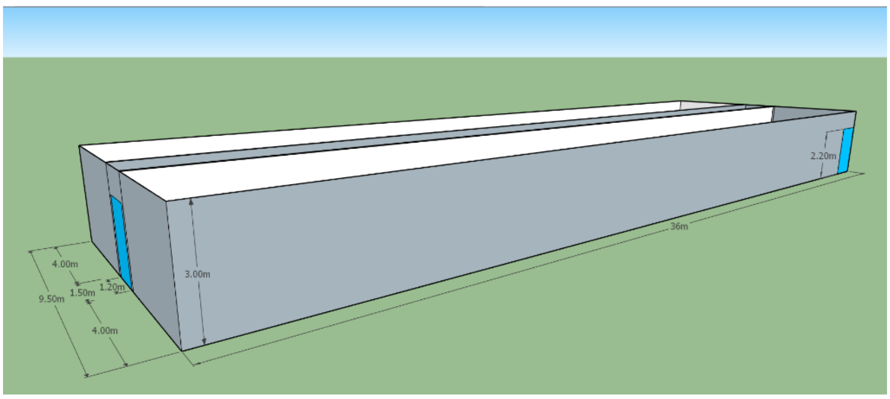

Figure 8: Simulation model with Dimensions

5. Results and Discussion

For the calibration procedure, data from fieldwork at the hostel was compared with both the data from the artificial sky and simulation and the differences calculated. The results of the differences are listed and given in Table 3 below and graphed in Figure 9. As can be seen in the fieldwork data, DF values from the artificial sky model and the radiance simulation model was found to be in similar patterns with the fieldwork data with differences of less than 10%. Therefore, one can conclude both the artificial sky scaled model experiment and the Radiance simulation could further be used to expand and further study on corridor lighting with confidence.

The results in Table 3 show that calculated DF values are less than 1% in the corridor of Aman Damai building is below the standard recommendation. The outdoor illumination level can reach up to 60,000 lux 70,000 lux and 80,000 lux during December, June, and March respectively which considered as the critical months for daylight levels in Malaysia. Moreover, more than 100,000 lux of outdoor illuminance was recorded during clear skies in Malaysia (Al-Obaidi et al., 2014). Therefore, the daylight in Malaysia is ample enough to provide sufficient visibility for movements to be carried out for daily routines.

Table 3: Summary of Daylight Factor results

	Average of % DF				
	Point 1	**Point 2**	**Point 3**	**Point 4**	**Point 5**
Aman Damai hostel	0.16	0.011	0.006	0.011	0.14
Artificial sky model	0.15	0.010	0.0065	0.010	0.13
Radiance	0.17	0.01	0.0055	0.01	0.15
% Differences between field work and Artificial sky	6.25%	9 %	- 8.3%	9 %	7.14%
% Differences between field work and simulation	- 6.25%	9 %	8.3 %	9 %	- 7.14%

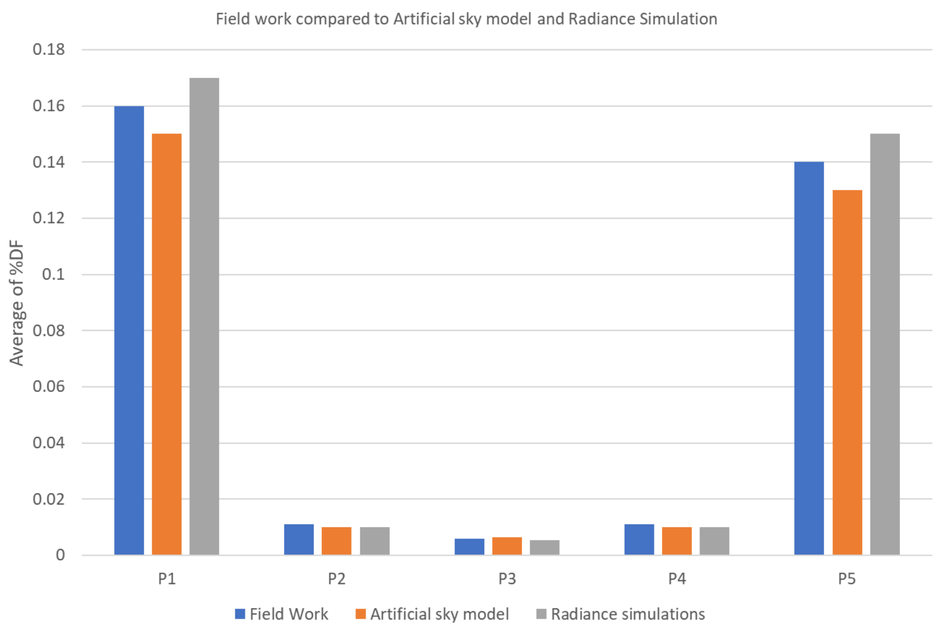

Figure 9: Comparison of Fieldwork results with Artificial Sky and Radiance Simulation results.

6. Conclusions

In general, proper design of daylight to illuminate deep spaces is a major challenge in the design process of buildings. The proper design of daylighting will result in major reduction in lighting energy consumption as well as total energy consumption. Besides, daylighting will have a positive impact on occupants' health, satisfaction, and performance. This paper discussed calibration of methods using scale model and simulation in Internal enclosed corridors for reducing energy consumption, and how the % DF less than standard recommended can improve the level and distribution of daylight into the corridor area. In the research methodology, three methods were studied to use in corridors.

This paper could be extended in the path of using Borrowed daylight technique in Internal enclosed corridors for reducing energy consumption, and how the borrowed lights from corridor walls can improve the level and distribution of daylight into the corridor area. Further studies are recommended to investigate more variables. Investigating the potentials for fiber optic lighting for interior corridors can be addressed. Also, it is recommended to investigate different types of exterior windows which transfer light to corridors and the influence of corridor width and room depth and its effect on borrowed daylight.

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