

## GLOBAL ILLUMINATION SIMULATION TECHNIQUE IN DEVELOPING GUIDELINES TO MITIGATE VEILING REFLECTION IN INDOOR SWIMMING POOLS

Thomas Chan<sup>1</sup>, Kenneth Li<sup>1</sup>, Kelvin Tong<sup>1</sup> and Ernest Tsang<sup>1</sup>

<sup>1</sup>Parsons Brinckerhoff (Asia) Limited, Kowloon, Hong Kong Special Administrative Region

### ABSTRACT

Increasing daylight into indoor swimming pools creates a warm and sunny environment for swimmers and provides connections with the outdoor environment. However, lifeguards report that veiling reflection from the water surface, a result of this daylighting, limits visibility into pool basins. Thus, the veiling reflection caused by increased daylight affects the safety of swimmers.

A study was conducted to develop a Design Guidelines, intended for the Hong Kong government and local professional practitioners, to reduce the occurrence of veiling reflection on water surfaces. This study is considered a pioneering Consultancy Study Project. Because visual ability is a subjective feeling and difficult to predict, and because there are currently no existing key performance index available for comparison, this study employs a novel approach to overcome these setbacks. The Study employed both field visit and simulation technique in alleviating the veiling reflection. RADIANCE was selected for conducting natural and artificial light simulation. This paper focuses on the role of simulation in providing quantitative and qualitative information for the Task Force members from the government and stakeholders to determine the subjective judgments.

This study has demonstrated the use of simulation technique in developing Design Guidelines and consultations throughout the engagement process. Recommendations for further study are suggested.

### INTRODUCTION

Swimming is one of the most favourable sport activities in Hong Kong. According to the Census and Statistics Department (2011), swimming was ranked as the fourth most favourable sport. Swimming pools were ranked as second when considering sport facilities most often used in the vicinity of home. More importantly, about 13.5% of Hong Kong citizens consider that among all city sport facilities, swimming pools are the most insufficient.

Today, many swimming pools are currently being designed and constructed. To cope with the sustainable development and local green building practices, natural ventilation and daylighting design features have become two of the major design considerations in swimming pool development. However, one of the induced problems for these

environmentally friendly designs is the problem of veiling reflection.

Veiling reflection reduces the visibility of those above a pool looking in. In effect, lifeguards are rendered unable to see swimmers underneath the water surface. This kind of reflection is caused by a higher luminance of reflected light from the water surface compared with the pool basin. It makes objects underneath the water surface difficult to see or even invisible. One of the potential risks of veiling reflection is reducing the visibility of lifeguards and hence delaying the time for life rescue.

Existing indices such as unified glare rating and daylight glare index are used for artificial and natural lighting, respectively. However, these kinds of performance indices are not applicable to handle veiling reflection in swimming pool.

In view of life safety, the Architectural Services Department (ArchSD) and Leisure and Cultural Services Department (LCSD) decided to develop a design guideline to alleviate the problem of veiling reflection in swimming pools.

The backgrounds of this study, roles and settings of simulation in the project and its major findings from simulation are discussed below.

### APPROACH OF THE STUDY

To the best understanding of the Consultant Team and Task Force members, no Design Guidelines exist specifically addressing the problem of veiling reflection on water surface in swimming pools. A set of new Design Guidelines is therefore needed. The project is divided into three major stages:

1. Research Study Stage
2. Consultations Stage with Stakeholders
3. Development Stage of Design Guidelines

#### **Research Study Stage**

There are three major elements in the Research Study Stage. A literature review on local and international standards and relevant design guidelines was carried out. In total, 17 standards were studied. The design parameters related to artificial and natural lighting were analyzed.

Site visits to eight swimming pools were conducted to identify the potential risks associated with veiling reflection. During the process, interviews with the managing staffs and lifeguards were conducted. Even though some physical phenomena were

observed during these site visits, a full conclusion is not appropriate without a systematic and fair analysis. Hence, simulations were also performed for different swimming pool arrangements.

### Consultations with stakeholders

A Design Guidelines draft was written based on the Research Study Stage findings. Apart from technical analysis, it is more important to ensure that the proposed Design Guidelines can address the concerns of different stakeholders such as designers, management staffs, swimmers and lifeguards. The impacts of veiling reflection design varies across parties. Consent from different stakeholders was required before finalisation of the Design Guidelines. As a result, four focus group consultations and three additional site interviews were conducted in order to explain findings and to seek consent from the aforesaid stakeholders. The total number of interviewees and consultees numbered over 100.

### Development of Design Guidelines

Findings from the Research Study Stage and views collected via the Consultation Stage were used to finalise the contents of the Design Guidelines. The Design Guidelines covers the design considerations from site selection, swimming pool geometrical settings and lighting system design. The Guidelines is a standalone document for building professionals to follow.

The process is outlined in Figure 1.

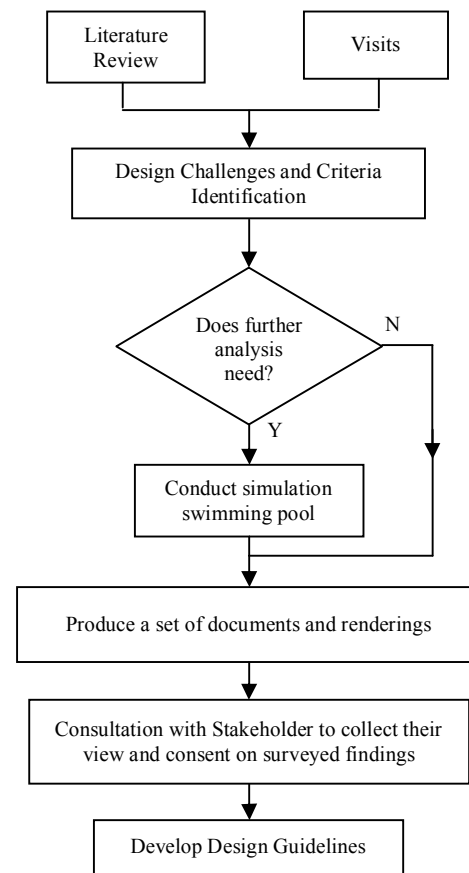


Figure 1 Simplified flow chart shows the process of Consultancy Study

### Constraints of the project

This Consultancy Study was aimed at finishing all the works within 8 months including all research study, consultation and guideline development. Hence it is difficult for the team to establish a well-developed key performance index to measure veiling reflections.

### ROLES AND SETTINGS OF SIMULATION

As described above, simulation is a useful tool in this research study. Observations from swimming pools and the impacts of different design parameters were evaluated by the computational package. Apart from research study, simulation package is employed in the consultation stage of the project. The simulation can help the consultant team to visualize the impacts of different design intents in a generic swimming pool following the design recommendations of the proposed Design Guidelines. It is an essential step in providing an overall impression of the design pool and gaining stakeholder support on the proposed Design Guidelines. The settings of simulation model are described below:

### Sky conditions

This numerical study is aimed at providing design information under different design conditions. Hence, it is not worth it to conduct an hour-by-hour simulation based on actual weather data, especially considering resource and time constraints. The CIE Standard General Sky model (CIE, 2003) is considered to be the most appropriate sky model and is therefore adopted in this numerical study.

The zenith luminance ( $L_z$ ) is normalized to the horizontal diffuse illuminance of the whole sky ( $E_{vd}$ ), which is a more stable measure than the luminance of a single patch of sky. The horizontal diffuse illuminance and direct illuminance can be obtained by Kittler et al. (1998).

In Hong Kong, sky luminance distribution patterns have been measured since 1999 at the City University of Hong Kong. Li et al. (2011) studied the sky luminance distribution pattern and found that General Sky no. 1, 8 and 13 are having the highest frequencies of occurrence among the overcast, intermediate and clear skies. In this numerical study, the simulations were conducted in accordance with the above sky types and the simulation method proposed by Greenup (2003).

### Selected relative solar position

The proposed Design Guidelines is intended for the design of swimming pools in Hong Kong. If the hour-by-hour simulations for different orientations are required, it is very time consuming and unnecessarily complicates the case. Hence, a relative solar position approach is proposed for the evaluation in this study. Figure 2 depicts the cumulative frequency of solar altitude in Hong Kong. The sampling is based on the frequency of occurrence. Table 1 shows the selected relative solar position for this analysis. The root-mean-square difference is of 7.1°.

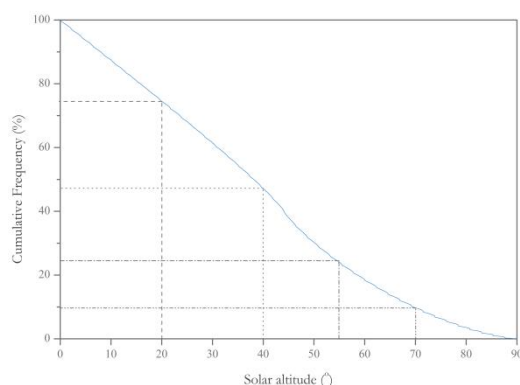


Figure 2 Cumulative frequency of solar altitude in Hong Kong

Table 1 Relative solar position for simulation

Solar Altitude bin	Mid-Solar altitude	Relative Azimuth
0°-20°	10°	0°, 20°, 40°, 60°, 80°, 100°, 120°, 140°, 160°, 180°
20°-40°	30°	0°, 20°, 40°, 60°, 80°, 100°, 120°, 140°, 160°, 180°
40°-55°	47.5°	0°, 20°, 40°, 60°, 80°, 100°, 120°, 140°, 160°, 180°
55°-70°	62.5°	0°, 30°, 60°, 90°, 120°, 150°, 180°
70°-90°	80°	0°, 45°, 90°, 135°, 180°

### Simulation engine and settings

RADIANCE, a software developed by Lawrence Berkeley National Laboratory (LBNL), was selected as the simulation package for this numerical study. RADIANCE is an open-source computer program (LBNL, 2002) and is a collection of fifty-odd programs (Ward and Shakespeare, 1998). This computer program provides calculation, rendering, image processing and display. The system was originally developed as a research tool to explore advanced rendering techniques for lighting design. RADIANCE uses ray-tracing approximation in light. This numerical study was conducted using RADIANCE 4.1.

The key simulation parameters for illuminance determination are the number of reflections and the resolution of the inter-reflection for calculation. These parameters are known as the ambient parameters. In this study, visual inspection is more important compared to accurate numerical value. Renderings are generated for detail analysis, and settings are optimized for speed with a reasonable accuracy. The parameters are listed in Table 2.

Table 2 Ambient parameters settings for rendering generation

Ambient Parameters	Value
Ambient division	1024
Ambient sampling	512
Ambient accuracy	0.08
Ambient resolution	512
Ambient bounces	6

### Swimming pool settings

In Hong Kong, there are two major types of swimming pools. One is a standard pool for competition use with a dimension of 25m X 50m. The variation of this type of swimming pool is relatively small. On the other hand, leisure and recreational pool has several different sizes. According to the recommendation of various client departments, it was recommended to study a 12.5m

X 25m swimming pool. Hence, two different generic pools were evaluated in this Study. The first one is a standard pool of 25m (W) x 50m (L) x 1.9m (D) as shown in Figure 3 and the other is a leisure pool of 12.5m (W) x 25m (L) x 1.25m (D) (Figure 4). The reflectance of different surface and geometrical arrangement are based on site surveys and in reference to international standards. The values are tabulated in Table 3.

Table 3 Design parameters set for computer simulation of generic swimming pool

Design Parameters	Value
Building Height	6m
Window Height	3m
Window Transmittance	0.4
Surface Reflectance	
Ceiling	0.7
Wall	0.5
Floor	0.2
Marks	0.3
Basin	0.7

Where parameters A and B in Figure 3 and 4 are varied, the minimum value for A is 3m and B is 1.5m. For simulating the condition of the water surface, there are two major schools of thought. The first school of thought prefers using still water (Standard Australia, 2007). The other considers turbulent water to be more meaningful (CIE, 1984). In this study, the water surface has a variation of 20° to surface normal which is according to the recommendations in CIE (1984).

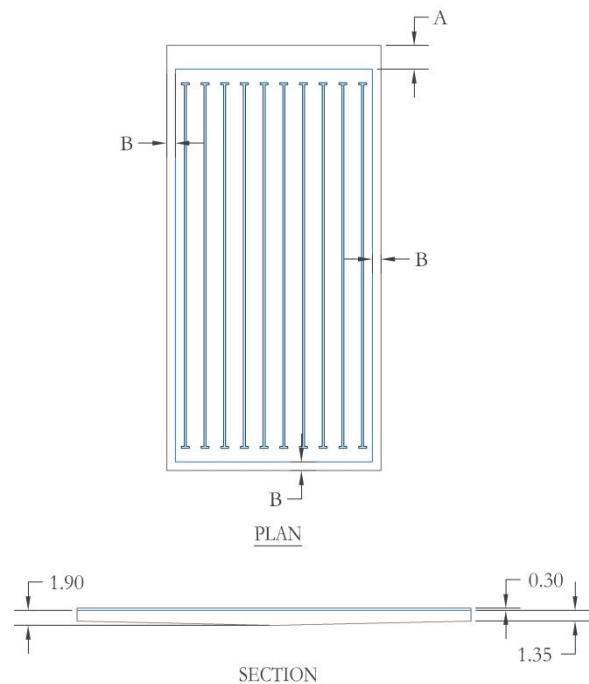


Figure 3 Dimension of standard pool

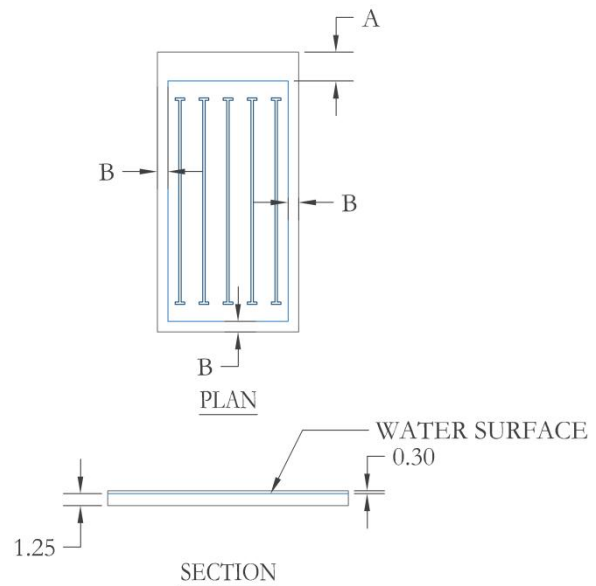


Figure 4 Dimension of leisure pool

There are seven types of window arrangements considered in this study. The wall number is shown in Figure 5 and the arrangement is shown in Table 4. Since both high-level and low-level windows need to be studied, over 7,000 sets of simulation are required. Figure 6 shows the recommended location of lookout posts based on the information suggested by the clients department. Taken together, over 40,000 renderings were generated by RADIANCE.

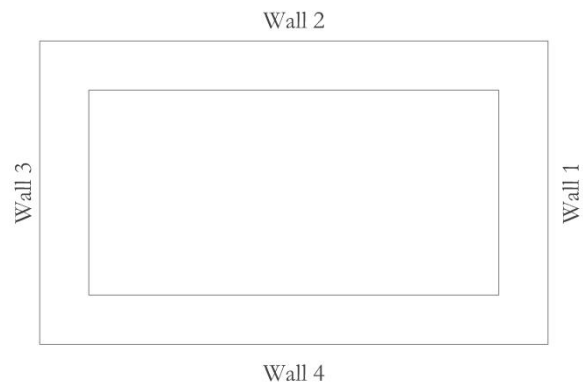


Figure 5 Wall reference for window allocation

Table 4 Allocation of window on wall

Case	Window opening on wall			
	Wall 1	Wall 2	Wall 3	Wall 4
1		•		
2				•
3	•		•	
4		•		•
5	•	•	•	
6	•		•	•
7	•	•	•	•

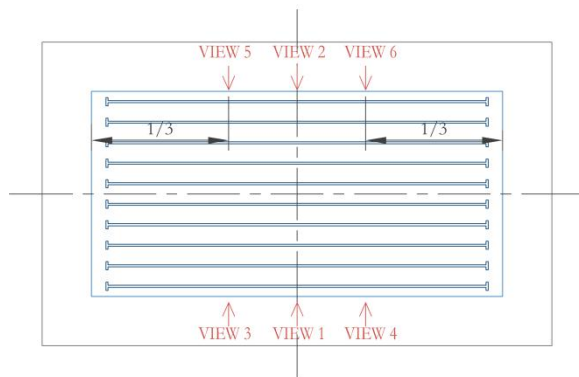


Figure 6 Lookout post for renderings generations

### SIMULATION FINDINGS

Based on the literature review and site visits to existing swimming pools, major design parameters affecting indoor lighting environment were identified. Parameters include angle of incidence, level of windows, horizontal illuminance level, uniformity, underwater lighting design, colour temperature, and contrast between opening and surroundings.

The following section describes parameters related to window location and the employed simulation technique. It also discusses implications to the veiling reflection on the water surface of the swimming pool.

#### Clearance between pool edge and window

It is widely understood that the distance between pool edge and window wall has significant implication on the veiling reflection of interior water surface. It is believed that a longer distance of setback can reduce the light intensity on the water surface. A shorter distance between the pool edge and window (Figure 7) produces a greater amount of veiling reflection than that of a longer clearance (Figure 8). Thus, in the proposed Design Guidelines, minimum required setback is twice of the window-top height.

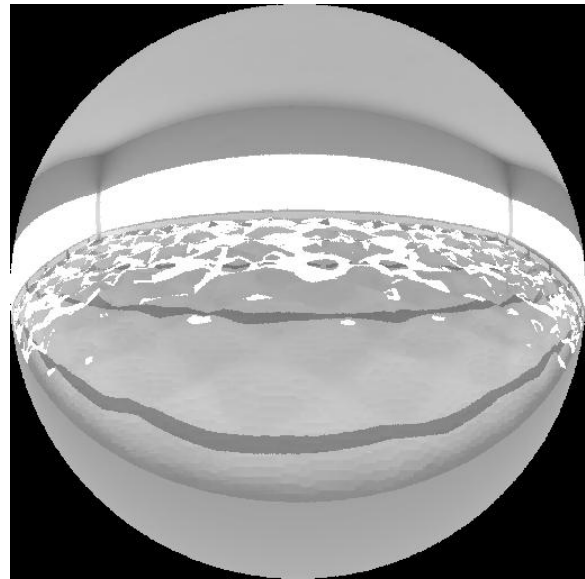


Figure 7 Width of pool deck is 1.5m

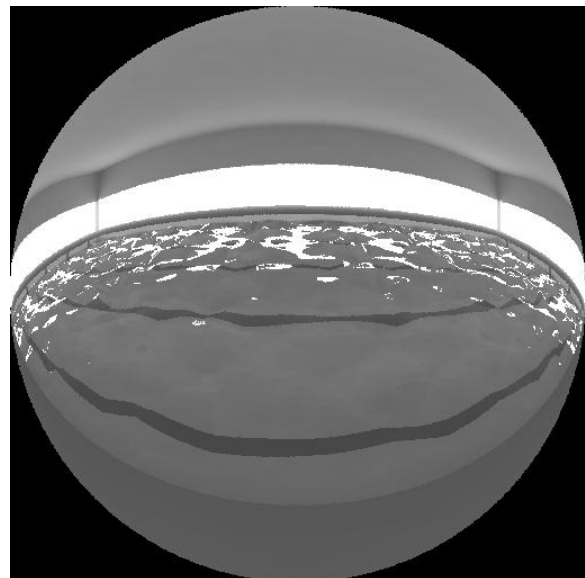


Figure 8 Width of pool deck is 6m

#### Surface reflectance of pool basin

Surface reflectance of the pool basin plays a crucial role in dealing with veiling reflection and the reflected image formed on the water's surface. The Lifesaving Society (n.d.) stated that both colour of basin and depth of pools affect the ability of lifeguards to see manikins on the bottom of pools. As the reflectance of pool basin surface increases, more light is reflected from the bottom of the pool. Hence, contrast between the pool basin and its surroundings (including the luminance flux on water surface) decreases. As the contrast lessens, the area affected by veiling reflection decreases as well; the reflected image is less clear thereby reducing distraction—reflections are obviously reflections and swimmers can be more easily seen. This enables lifeguards to carry out their duties.

Figure 10 shows a rendering of a swimming pool with a pool basin reflectance of 0.7 while Figure 8

displays a reflectance of 0.5. It can be seen that the lower the surface reflectance, the more clear the reflected image.

It is worthwhile to notice that a higher surface reflectance for pool basin has a large allowance on the reflectance other surfaces such as wall and ceiling without forming a noticeable reflected image on water surface. A series of simulation was conducted and a set of recommended surface reflectance is suggested based on the simulation results.

Rendering generated by different combination of surface reflectance was used in consultation and allow the stakeholder to express their feelings.

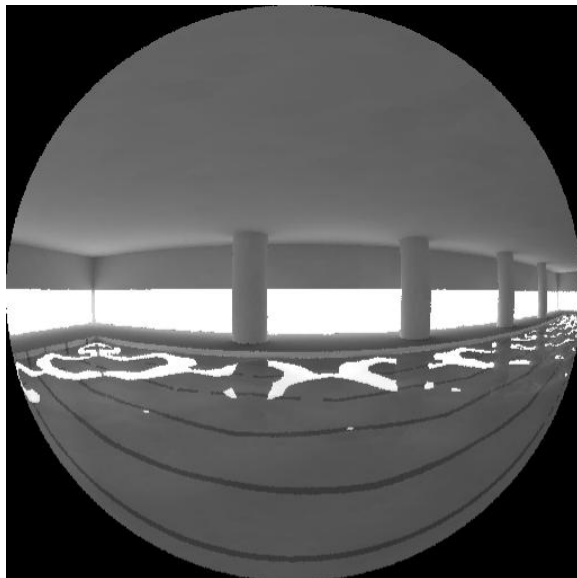


Figure 9 Swimming pool with a pool basin of surface reflectance 0.7

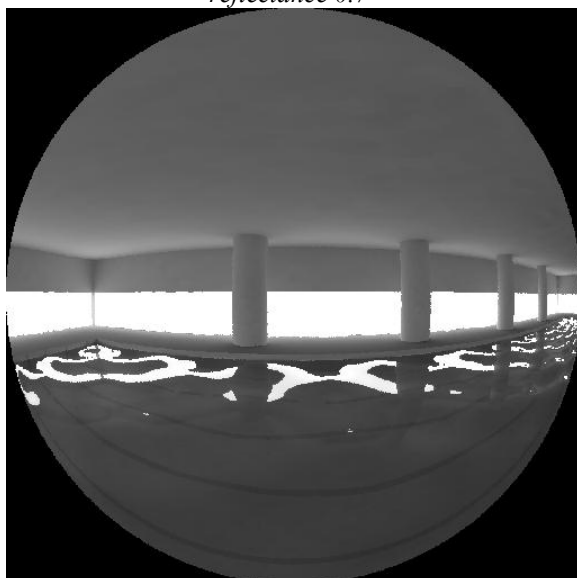


Figure 10 Swimming pool with a pool basin of surface reflectance 0.5

### Orientation of windows

The location of windows relative to lifeguards is one of the most critical factors in determining the seriousness of veiling reflection. It is noted that windows located directly opposite of the lookout post creates large amount of veiling reflection as shown in Figure 11. In view of this, it is not advisable to locate a window directly opposite the lookout post; doing so creates a life safety problem. If windows are needed, it is more preferable to open these windows at the short end (as shown in Figure 12). The veiling reflection will then be limited to a small region at the end sides of the pool. Usually, these locations have shallower water. It is expected that safety issues can be largely reduced.

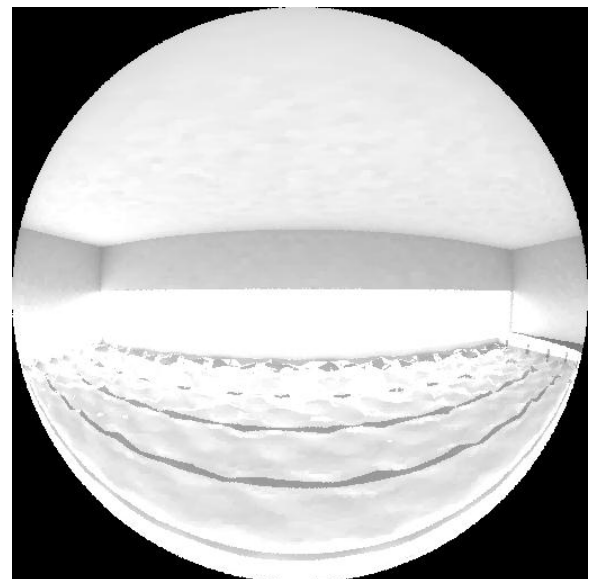


Figure 11 Large amount of veiling reflection is formed by window opposite to the lookout post

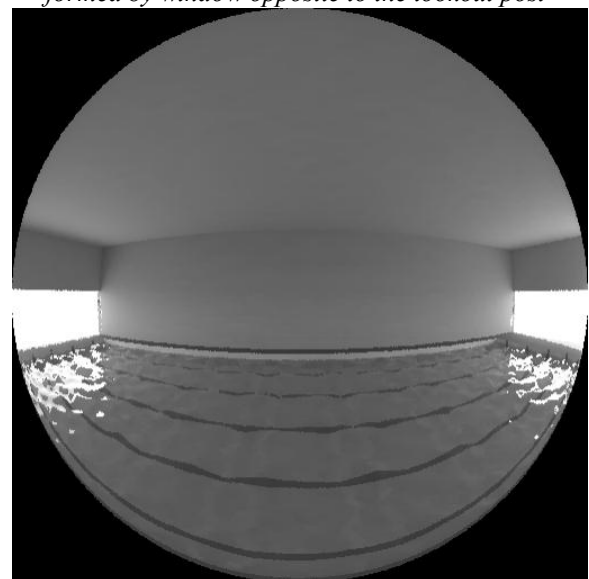


Figure 12 Less amount of veiling reflection is formed on short end window

### Skylight

During the site visits to the swimming pools, it was found that increasing the glazing area, particularly by incorporating skylights into swimming pool design, can reduce the veiling reflection on the water's surface. As more lighting enters the pool via the skylight, it can lighten the pool basin and increase the luminance flux reflected from pool basin, thus alleviating the veiling reflection. In this study, different skylight arrangements were simulated by changing window transmittance, skylight transmittance and skylight to roof ratio. The simulation uncovered a general rule: that the transmittance of a skylight should be higher than that of a side window, and the skylight should not be less than half of the roof area. It is noted that if the transmittance of skylight is significantly less than that for the side window, no matter how large the skylight is, veiling reflection cannot be prevented. This effect can be best illustrated by Figure 13 and Figure 14. In Figure 13, even though a large skylight is provided, if the skylight's transmittance is lower than that of the window, veiling reflection still occurs. Figure 14 shows that if the transmittance of a window is smaller than that of a skylight, even though the skylight to roof ratio is small, the veiling reflection does not form.

The setting of the skylight was also provided to stakeholder for their comment. Suggested design recommendations are: 1) the skylight to roof ratio should be 60% or more, 2) the transmittance of skylight should be higher than the side window by 0.2 and 3) the transmittance of window must be lower than 0.6.

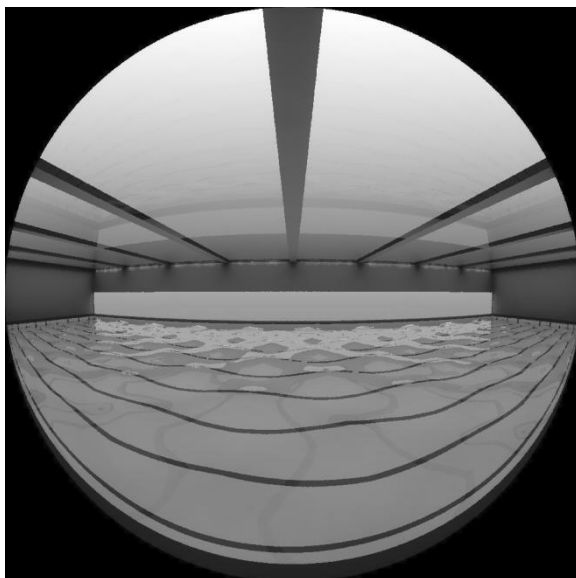


Figure 13 Veiling reflection occurs (windows transmittance = 0.9, skylight transmittance = 0.6, skylight to roof ratio = 0.9)

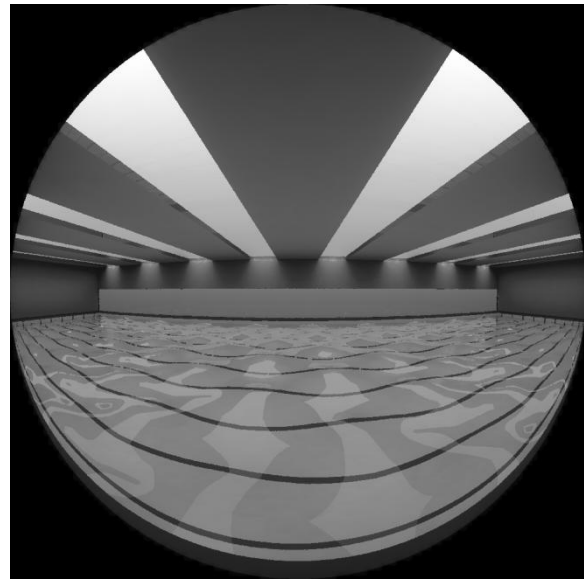


Figure 14 Veiling reflection does not occur (windows transmittance = 0.4, skylight transmittance = 0.9, skylight to roof ratio = 0.4)

### USE OF SIMULATION DURING THE ENGAGEMENT PROCESS

It is also important to convey the information found in this research study to non-building professionals. For the public, they are more interested in the performance of swimming pool in accordance with the proposed Design Guidelines. It is observed that the educated public is not satisfied with photorealistic-renderings commonly found in promotion brochures. Thus, the physical-based renderings which can reflect the "true" performance are welcomed. In this study, a model design according to the guideline as shown in Figure 15.

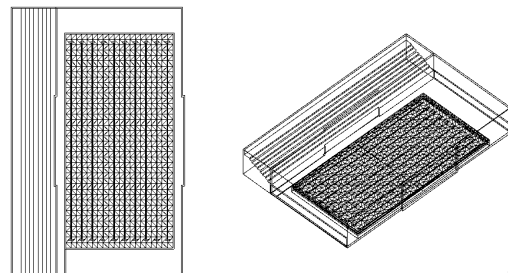


Figure 15 Swimming pool model design according to proposed design guideline

In Figure 16, a rendering of the above model is provided. It is found that the rendering can help the Consultant Team and Task Force members to explain their ideas and considerations to the public clearly. Also, it can help the stakeholders to have reasonable expectations and a realistic understanding of the performance of swimming pool design according to the proposed Design Guidelines.

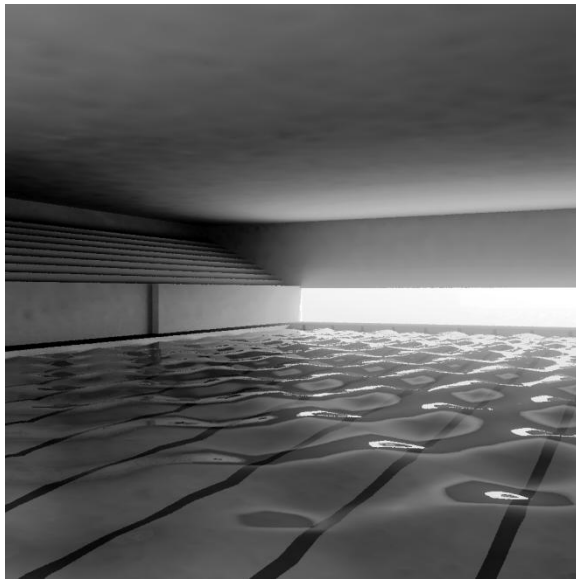


Figure 15 Rendering used to explain the performance to the public

## CONCLUSION

The paper reviews the importance of employing simulation in different stages of developing a Design Guidelines for indoor swimming pools to handle veiling reflection and other related glare problems. In the development stage, simulation can assist the consultant team and Task Force members to understand and determine the parameters affecting veiling reflection and settings the design criteria. Major findings of the research study obtained through simulation technique were briefly discussed. The paper also provides the background of using advanced simulation package in the engagement process. It found that renderings generated by computer simulation could provide more information to stakeholders and help them in selecting the most appropriate design criteria. Since the scope of this paper does not include a discussion of the proposed Design Guidelines in detail, relevant findings from literature review, site visits and design recommendations are not covered. Interested parties can find the Design Guidelines on the website of related departments.

This study is aimed at developing a user-friendly Design Guidelines. So the uses of simulation package in design process are not discussed in this Design Guidelines. In the view of not enough of experts available locally for performing strong knowledge-based simulation, it is not appropriate to include performance-based approach for alternative compliance at this moment. It is proposed that performance indices accounting for solid angle of veiling reflection and luminance ratio between water surface and pool basin should be developed, and that guidance should be provided for daylighting simulation in the future.

## ACKNOWLEDGEMENTS

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