Pertanika J. Sci. & Technol. 25 (S): 287 - 298 (2017)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Ceiling Geometry and Daylighting Performance of Side Lit Historical Museum Galleries UnderTropical Overcast Sky Condition

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ABSTRACT

Safe level of daylighting for artefact conservation in historic buildings is a difficult task to achieve. Previous studies indicated that lighting problems in historic museum galleries were mainly due to unshaded walls that allowed direct sun penetration over the display areas. Ceiling geometry can also affect the daylighting performance significantly, particularly on the interior distribution of light. Malaysia, with hot and humid climate, and tropical sky conditions receives plenty of natural light all year around. The fluxes in natural lighting exposures confirm the need for strategic daylight control programme in the exhibition gallery. The study aims to assess the ceiling geometry contribution for four orientations; North, East, South and West through computer simulations. The research approach was based on comparisons between pitched and flat ceiling simulation output data. Further comparisons were performed with the recommended lighting limits for conservation of artefacts. The comparisons allowed better understanding of light damage issues and highlight the control of daylighting distributions through realistic predictive images and ceiling geometry designs. The results showed that the types of exhibits materials and its placement are affected by the ceiling geometry and constant changes in natural lighting exposure. The study confirms that ceiling geometry can act as a control mechanism with the environment physical features as part of preventive conservation criteria in the exhibition gallery. Thus, a systematic light-monitoring programme in the exhibition gallery is necessary to control illuminance level and cumulative exposure limits, for artefact preservation.

Keywords: Ceiling geometry, daylighting performance, historic building, tropical sky

ARTICLE INFO

Article history:
Received: 05 January 2017
Accepted: 17 January 2017

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ISSN: 0128-7680

INTRODUCTION

Adaptive reuse of a historic building for a museum or heritage facility can present certain challenges (Ahmad, Ahmad, & Talib, 2013). Corridors and balconies that are partially enclosed or fully opened with natural light penetration are among the main features of historic buildings that serve as exhibition spaces. Nevertheless, these favourable natural lighting conditions either accounted for energy conservation or enhancing the visual quality promoted severe threat on the artefacts. Studies have proven that many of the lighting issues in museum galleries were mainly due to direct sun penetration over the display areas (Ahmad, Ahmad, & Talib, 2012; Del Hoyo-Meléndez, Mecklenburg, & Doménech-Carbó, 2011; De Graaf, Dessouky, & Müller, 2014; Wilson, 2006). The introduction of daylit exhibition spaces in historic museum buildingscreates a much more complicated preservation problem due to theuntested quantity of light development and variability in illuminance level (Ahmad, Ahmad, & Talib, 2011). Therefore, the design of daylit exhibition spaces, either in a museum or as an integral part of a historic building, need to take consideration not only functional requirements but also preventive conservation planning to preserve every single artefact. Today, there is an urgent worldwide demand for energy saving and sustainability, where passive design with climatic responsiveness should be pursued in all building types (Alrubaih et al., 2013; Toledo, 2007). Toledo (2007), and Maekawa and Beltra (2004) highlighted that climate control can be achieved for both visitors' comfort and material conservation by enhancing their original architectural features.

Lighting Limits for Conservation of Artefacts

Based on the literature review on the recommended lighting limits for artefact conservation by the museums community for safe lighting levels (Thomson, 1990), the following classification is used for daylighting assessment and formed the basis to understand light damage issues in relation to the recommended lighting limits for artefact conservation:

i) For Category I- Highly responsive/Sensitive materials, ≤ 50 lux

   Example: Textiles, costumes, tapestries, paper, parchment, dyed leather, painted or dyed wood, natural history exhibits i.e., botanical specimens, fur and feathers.

ii) For Category II-Moderately responsive/ sensitive materials, ≤ 200 lux.

   Example: Oil and tempera painting, fresco, undyed leather, horn, bone, unpainted wood and lacquer, and some plastics.

iii) For Category III-Non-responsive/Non-sensitive materials, ≤ 300 lux

   Example: Metal, stone, glass, ceramics, enamel, and most minerals.

Ceiling Geometry

Previous research and reviews stated that ceiling geometryis an important part of the lighting scheme, which also effect daylight level and determine whether a space is well lit (Freewan, Shao, & Riffat, 2009; Freewan, 2010; Kim & Chung, 2011; Rakha & Nassar, 2011). Freewan (2010) investigated the accuracy of physical models and RADIANCE simulation in measuring daylight performance using the interactions of louvers and ceiling geometries. The simulation revealed that curved ceiling added to the daylighting uniformity and quality compared to a flat ceiling. Freewan (2010) also found that the curved, chamfered, arched, and sloped-down ceilings (except sloped-up ceiling geometry) improved the daylighting performance in June and December, as well as in March. The study also demonstrated that louvers performed better with curved and chamfered ceiling throughout the year. Furthermore, in other studies by Freewan, Shao and Riffat (2009), they found that curved ceiling improved the performance of alight shelf. The study found that both combinations improved uniformity where the illuminance level increased in the rear part and decreased in the front part of a room. Rakha and Nassar (2011) studied on performance optimization of ceiling form and found that curvilinear ceiling form achieved better daylighting uniformity compared to mesh ceiling form.

The purpose of this research is to explore the effects of ceiling geometries on a historic building's exhibition space with either pitched or flat ceiling on days with maximum and minimum daylight, which are 21 March and 21 December respectively as proposed by Shahriar and Mohit (2007) for peninsular Malaysia. A simulation output data using the reference case at West (existing) orientation and the interior reflectance values were further compared with the recommended lighting limits for artefacts conservation by the museums community for safe light levels. This study is to ascertain whether ceiling geometry can act as passive control mechanism with the environment physical features as part of preventive conservation criteria in the exhibition gallery. By assessing all the findings, the best possible conditions of room orientation and ceiling geometry for long-term preservation of museum artefacts under given sky condition are recommended.

MATERIALS AND METHOD

The study used validated RADIANCE software which is integrated in the IES<VE> programme to analyse the impacts of ceiling geometry provided with different room orientations on daylight level at work plane/exhibit height. The aim was to find the best ceiling geometry and room orientation conditions for daylight control. Radiance is a back-ward ray-tracing comprehensive programme that accurately predicts light levels and rendering that produces synthetic images that are realistic for all sky conditions (Ibrahim & Zain-Ahmed, 2007; Joarder, Ahmed, Price, & Mourshed, 2009).

The simulation parameters are as follows:

- Location: Latitude and Longitude of Melaka is 2° 11’ N and, 102O 14’ E at elevation 13 m
- Date and Time: 21 March and 21 December (10.00h, 13.00h and 16.00h)
- Sky condition: CIE Overcast sky
- Orientations: North, East, South and West
- Floor area: 43.4 m2 (1st floor)
- Pitched ceiling (H): 2.6 m min, 4 m (under pitch), Flat ceiling (H): 3 m
- Window-wall ratio (WWR): 20%
- Opened window: 100% transmittance
- Window sill (H): 900 mm
- Analysis grid: 4 measuring points (at horizontal point of 1 m (H) in all showcases)
- Against the Window Wall (AWW) reflectance: 90%
- Opposite the Window Wall (OWW) reflectance: 60%
- Ceiling Reflectance: 20%
- Floor Reflectance: 30%
- Showcase with wood framing - 6mm clear glass: 80% transmittance
- Showcase back panel reflectance: 30% (Velvety red fabric)

For simulation analysis, a flat ceiling will be examined and compared to the reference case gallery with pitched ceiling as shown in Figure 1; which is considered as the base case in all the cases. All internal surface reflectance values were kept constant. All models had the same floor area, length and width but the ceiling heights values were of different heights. Average daylight measurements were calculated on work plane height (exhibit height) at horizontal point of 1 m (*H*) in all showcases along against and opposite window walls provided with varying room orientations. The source of daylight is side lit from the windows.

Figure 1 shows the positions and configurations of the four showcases, they are labelled as showcases A, B, C and D. The wall along showcases A and B is called the AWW (against window wall), while the wall along showcases C and D is the OWW (opposite window wall). For simulation assessment, the ground floor space underneath the study gallery was hidden as it will not affect the simulation output and will only lengthen the simulation process unnecessarily (Joarder et al., 2009).

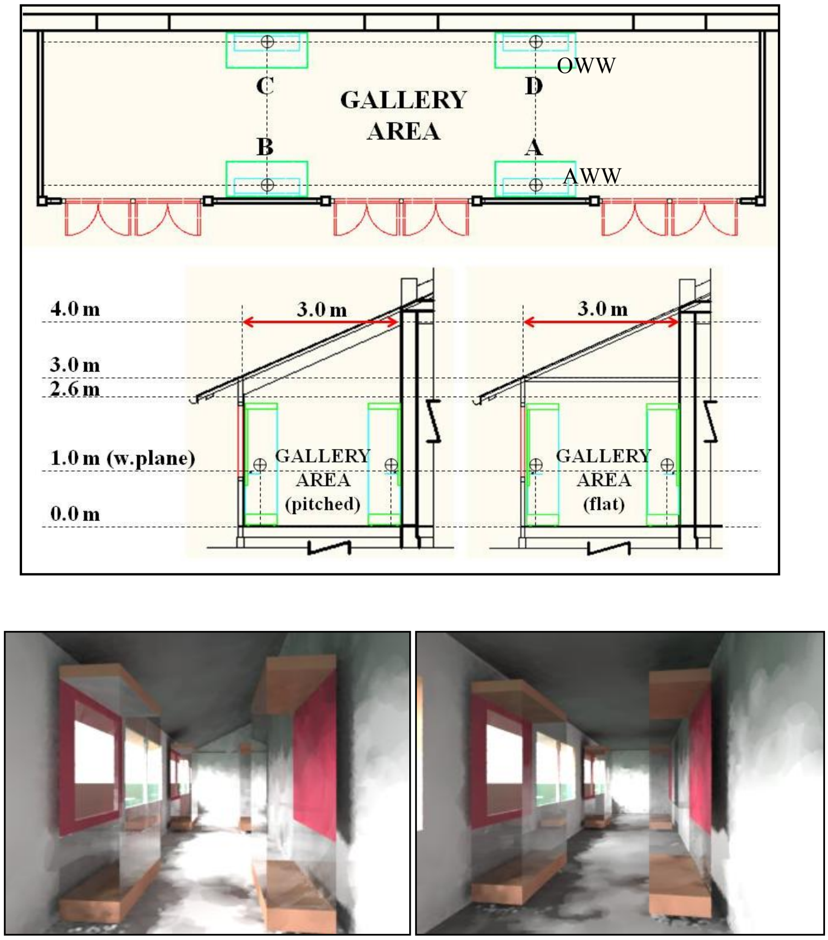

Figure 1. Simulated gallery area dimensions and measuring points for pitched and flat ceiling

RESULTS AND DISCUSSION

Average Illuminance Level (Lux) on Work Plane (Exhibit Height) at Horizontal Points of 1 m (H)

Table1shows how the illuminance levels changed at 10.00h, 13.00h and 16.00h in the showcases at four types of room orientations served with different ceiling geometries on 21 March and 21 December for both AWW and OWW at 1 m planar surfaces.

Table 1
Results of simulated average daylight distribution at showcases (AWW & OWW) of four room orientations West (existing), East, South and North at 10.00h, 13.00h and 16.00h on 21 March and 21 December under overcast sky condition

	Against Window Wall (AWW) at 1m H-horizontal						Opposite Window Wall (OWW) at 1m H-horizontal					
	21 March			21 December			21 March			21 December		
Ceiling Type	Pitch Lux	Flat Lux	% change	Pitch Lux	Flat Lux	% change	Pitch Lux	Flat Lux	% change	Pitch Lux	Flat Lux	% change
10.00h												
WEST	12	12	0	12	9	-25	81	76	-6	92	77	-16
EAST	12	11	-8	12	9	-25	81	71	-12	92	76	-17
SOUTH	21	16	-24	12	10	-17	105	66	-37	76	86	13
NORTH	19	10	-47	15	15	0	82	79	-4	90	86	-4
Max	21	16		15	15		105	79		92	86	
Min	12	10		12	9		81	66		76	76	
13.00h												
WEST	23	15	-35	20	15	-25	117	86	-26	123	95	-23
EAST	23	14	-39	20	12	-40	117	91	-22	123	93	-24
SOUTH	23	20	-13	23	17	-26	132	123	-7	146	114	-22
NORTH	20	31	55	21	16	-24	131	96	-27	146	112	-23
Max	23	31		23	17		132	123		146	114	
Min	20	14		20	12		117	86		123	93	
16.00h												
WEST	18	12	-33	12	8	-33	112	94	-16	105	62	-41
EAST	18	12	-33	12	9	-25	112	97	-13	105	73	-30
SOUTH	18	12	-33	20	15	-25	121	65	-46	98	58	-41
NORTH	22	15	-32	15	10	-33	90	96	7	84	96	14
Max	22	15		20	15		121	97		105	96	
Min	18	12		12	8		90	65		84	58	

Figures 2 and 3 illustrate the readings captured in Table 1 by showing the comparisons between pitched and flat ceilings with isolux analysis at South facing orientation on 21 March and 21 December respectively. It can be seen that the AWW records lower illumination readings than the OWW for all conditions. The pitched ceiling also captures higher illumination distribution in the interior space than the flat ceiling. This means more light is distributed on the planar surfaces at 1 m above the floor, which represents the horizontal exhibit surfaces.

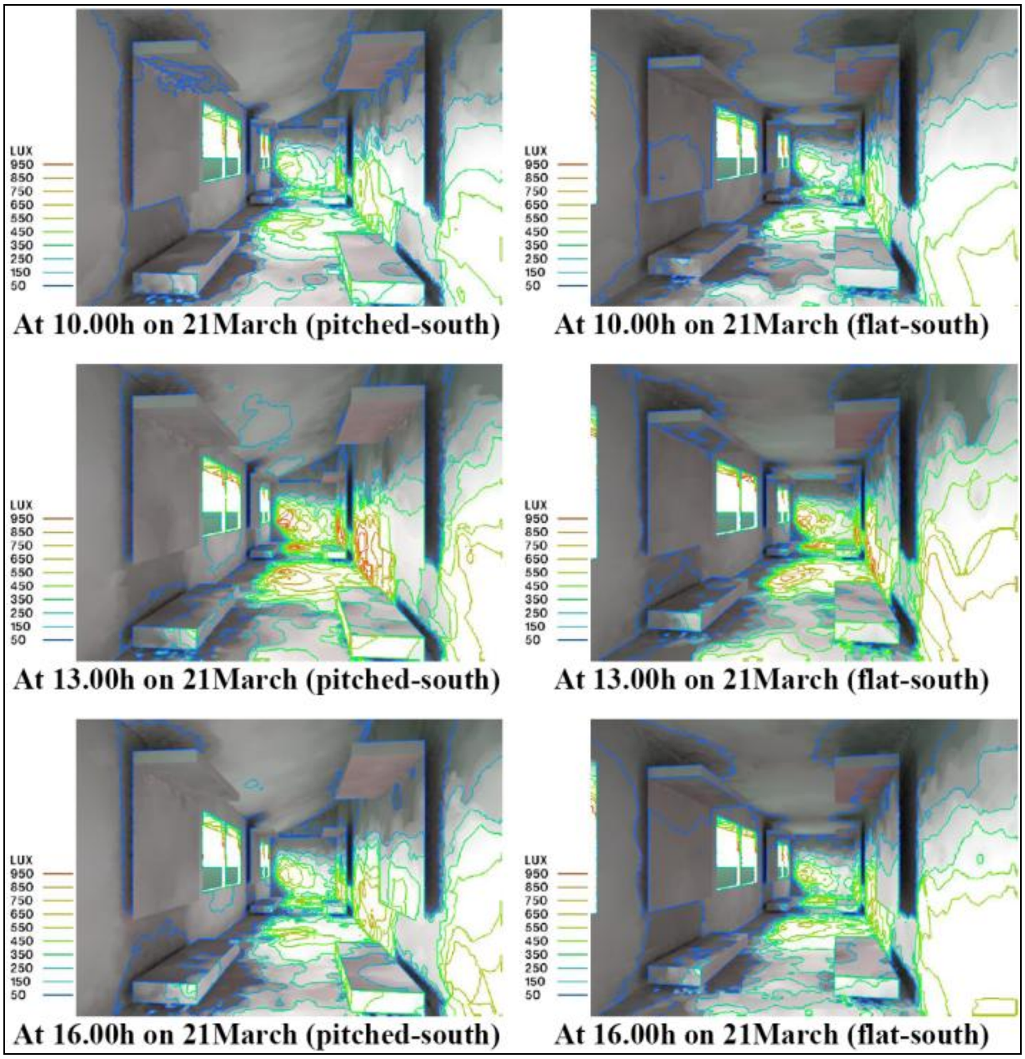

Figure 2. Comparison between pitched and a flat ceiling with isolux analysis on 21 March at 10.00h, 13.00h and 16.00h under overcast sky condition

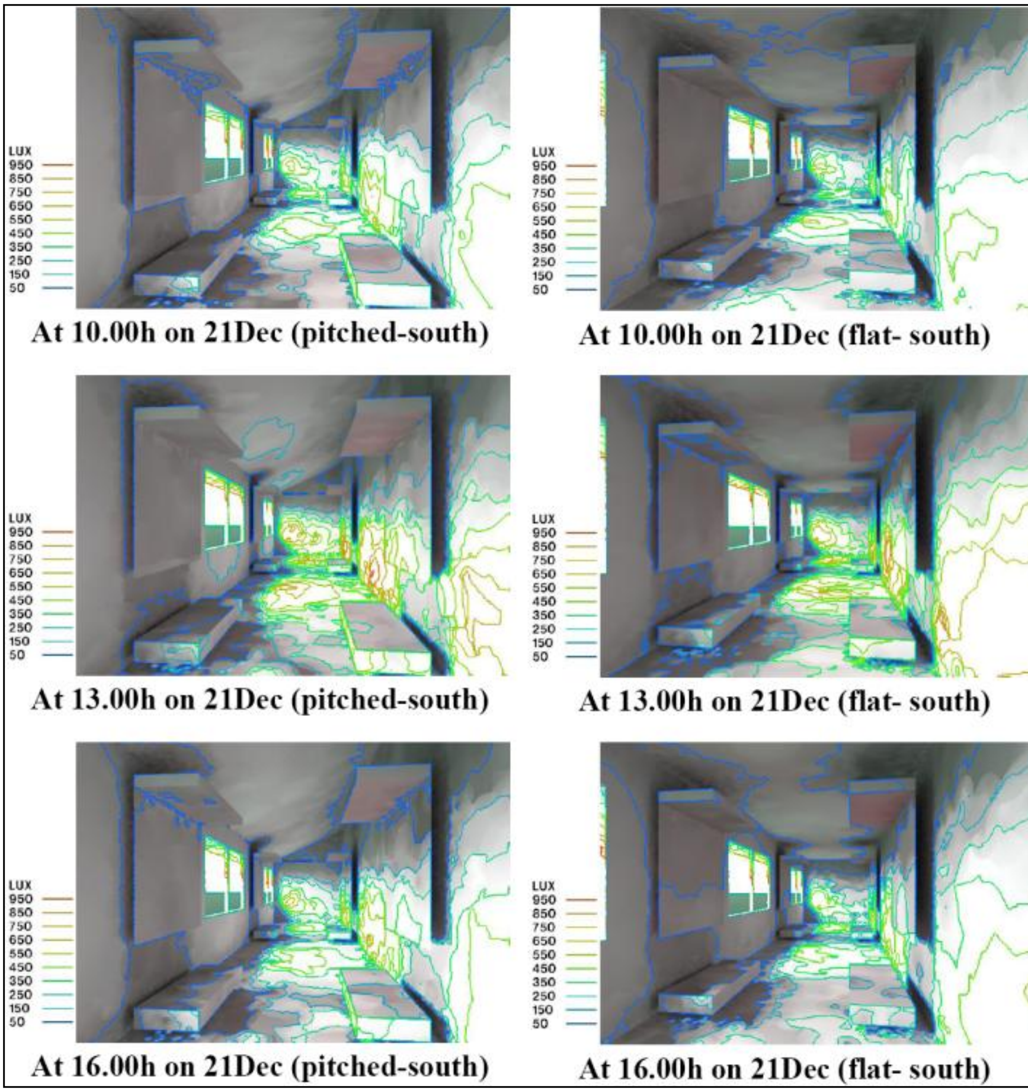

Figure 3. Comparison between pitched and a flat ceiling with isolux analysis on 21 December at 10.00h, 13.00h and 16.00h under overcast sky condition

Against Window Wall (*AWW*) for Showcases A and B

Table 1 shows that for the flat ceiling at *AWW* showcases A and B at East, South and North orientations, there are decreased illuminance level between -8 and -47% (10 to 16lux) in the morning at 10.00h on 21 March compared with the pitched ceiling gallery. Meanwhile, the reduction of illumination between -17 and -25% (9 to 10lux) is observed on 21 December for East, West and South orientations. During this hour, both pitched and flat ceiling at South orientation registered the highest illuminance level of 21lux and 16lux on 21 March respectively. However, the North orientation registered similar and highest illuminance level of 15lux on 21 December for both types of ceiling.

At 13.00h, Table 1 shows that the flat ceiling gallery registers reduced illuminance level between -13 and -39% (14 - 20lux) at the *AWW* showcases A and B at East, South and West orientations on 21 March than the pitched ceiling gallery. Meanwhile, the results for 21 December show decreased illuminance level between -24 and -40% (12 - 17lux) at all orientations.

Table 1 also shows that on 21 March, the pitched ceiling gallery records the highest illuminance level of 23lux at East, West and South orientations respectively. Meanwhile, the highest illuminance level of 31lux is registered at North orientation on the same solstice when using the flat ceiling. On 21 December, both pitched and a flat ceilings register the highest illuminance level of 23lux and 17lux respectively at South orientation.

According to Table 1, at late afternoon (16.00h), the flat ceiling gallery registers decreased illuminance level between -32 and -33% (12 to 15lux) and between -25 and -33% (8 to 15lux) at the *AWW* showcases at all orientations on 21 March and 21 December respectively. Both pitched and a flat ceilings register the highest illuminance level of 22lux and 15lux respectively at North orientation on 21 March, whereas, the highest illuminance level of 20lux and 15lux are observed for pitched and a flat ceilings respectively at South orientation on 21 December.

The overall results show that the pitched ceiling interior has higher illumination than the flat ceiling on the *AWW* side as shown in Table 1 and Figures 2 and 3. Generally, the simulation analysis indicated that at the three indicated hours (10.00h, 13.00h and 16.00h), for both pitched and flat ceiling conditions, enabled exposure limit of below 50lux, 200lux and 300lux for categories I, II and III respectively to be sustained at *AWW* showcases throughout most orientations on both 21 March and 21 December.

Opposite Window Wall (*OWW*) for Showcases C and D

Table 1 shows that at 10.00h, on 21 March, the flat ceiling gallery records decreased illuminance level between -4 and -37% (66 to 79lux) at the opposite window wall (*OWW*) showcases C and D at all orientations compared to the pitched ceiling gallery. Meanwhile, decreased illuminance level between -4 and -17% (76-86lux) are observed at East, West and North orientations on 21 December.

At *OWW*, on 21 March, both pitched and flat ceilings register the highest illuminance level of 105lux and 79lux at South and North orientations respectively as shown in Table 1. It is observed that on 21 December, pitched ceiling registers the highest illuminance level of 92lux at both East and West orientations. Meanwhile, the highest illuminance levels of 86lux at both South and North orientations are observed when using the flat ceiling on the same solstice as shown in Table 1.

At 13.00h, on 21 March and 21 December, the flat ceiling gallery records decreased illuminance level between -7 and -27% (86 to 123lux) and between -22 and -24% (93 to 114lux) respectively at the *OWW* showcases C and Dat all orientations in comparison with the pitched ceiling gallery (Table 1). Table 1 also shows that at 13.00h, the *OWW* showcases served by both pitched and a flat ceiling register the highest illuminance level of 132lux and 123lux respectively at South orientation on 21 March. Pitched ceiling indicates the highest illuminance level of 146lux at both South and North orientations on 21 December, whereas, the flat ceiling gallery with South orientation shows the highest illuminance level of 114lux.

At 16.00h, the *OWW* showcases C and Din a flat ceiling gallery at East, South and West orientations register reduction of illuminance level between -13 and -46% (65-97lux) and between -30 to -41% (58 to 96lux) when compared with the pitched ceiling gallery on March and December solstices respectively (Table 1). The gallery with pitched ceiling indicated highest illuminance level of 112lux at both East and West orientations on 21 March, whereas, highest illuminance level of 97lux were observed at East orientation when using a flat ceiling during the same solstice. On 21 December, both East and West orientations registered highest illuminance level of 105lux for gallery with pitched ceiling and 96lux for flat ceiling at North orientation.

The results show that the pitched ceiling gallery interior has higher illumination than the flat ceiling on the *OWW* side as shown in Table 1 and Figures 2 and 3. However higher illumination levels are a concern when the exhibit are light sensitive and can be damaged when continuously exposed to too much illumination. The simulation analysis indicated that at 10.00h, 13.00h and 16.00h, both pitched and flat ceilings used for all orientations at the *OWW* showcases on both 21 March and December had exceeded the allowable exposure limit of 50lux for Category I-Highly responsive/Sensitive materials. However, the illumination levels are within the recommended lighting limits for artefact conservationfor categories II and III of below 200lux and 300lux for category II and III respectively.

CONCLUSION

This study presented a simulation analysis for flat and pitched ceiling geometry performance on daylight level under overcast sky conditions in Melaka, Malaysia. The chosen date and time were 21 March and 21 December to represent the month of maximum and minimum daylight respectively in Malaysia (Shahriar & Mohit, 2007).

Generally, the simulation analysis indicated that the illumination levels are within the recommended lighting limits for artefact conservationfor category I, II and III respectively to be sustained at *AWW* showcases throughout most orientations on both 21 March and December. However, the simulation analysis also indicated the illumination levels had exceeded the allowable exposure limit of 50lux for Category I-Highly responsive/Sensitive materials at the *OWW* showcases on both 21 March and December. Nevertheless, at these hours, both ceilings enabled exposure limit of below 200lux and 300lux for category II and III respectively to be sustained at *OWW* showcases for most orientations.

The acquired results from the reference case of pitched ceiling at West orientation served higher illuminance level compared to a flat ceiling type. Generally, the flat ceiling gallery recorded reduced illuminance level in both *AWW* and *OWW* showcases throughout both 21 March and December at most hours and orientations when compared with the pitched ceiling. Therefore, a gallery designed with a flat ceiling allows a significant degree of control towards the illuminance level compared to a pitched ceiling gallery. In design and preventive conservation applications, it is advisable to select a flat ceiling for Category II and III (moderately responsive material and non-responsive material).

Based on the above results, it can be concluded that most showcases at all orientations interacted with the ceiling geometry and responded to the sky vision angle and behaved more expressive in the reflected light direction and distribution. The results revealed that more care should be taken in the preliminary stage of design to avoid placement of light-sensitive materials and moderately sensitive materials in daylit areas, unless proper control and monitoring system are in place. The ceiling geometries assessment addressed major issues on the daylight behaviour and preservation of exhibits, which leave the architects and museum community with choices for design and monitoring strategies for long-term preservations of the exhibits.

The simulation assessment is presented as generic indications of light damage issues in relation to the recommended lighting limits for artefact conservation for specific interior geometry and reflectance values. Spaces with different configurations of form, ceiling geometry and reflectance values can be further researched to arrive at a more comprehensive result.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to IRMI, Universiti Teknologi MARA (UiTM) for funding the research under the Excellence Fund Research Scheme and International Islamic University Malaysia (IIUM) and participating museums for their kind support. Additional funding was provided by the Malaysian Ministry of Higher Education (MOHE) under the Fundamental Grant Scheme from the Ministry of Higher Education (FRGS 5/3 113/2015) for the publication fees.

REFERENCES

Ahmad, N., Ahmad, S. S., & Talib, A. (2013). Surface reflectance for illuminance level control in daylit historical museum gallery under tropical sky conditions. *Advanced Materials Research, Trans Tech Publications, 610*, 2854-2858.

Ahmad, N., Ahmad, S. S., & Talib, A. (2012). Luminous exposures and light-fastness survey in daylit historical museum galleries under tropical sky conditions. *Advanced Materials ResearchTrans Tech Publications, 488*, 1547-1552.

Ahmad, N., Ahmad, S. S., & Talib, A. (2011). Illuminance distributions, visual response and limits for conservation of exhibits in Admiral Cheng Ho Gallery, Malaysia. In *IEEE Symposium on Computers and Informatics (ISCI), 2011* (pp. 407-412). IEEE.

Alrubaih, M. S., Zain, M. F. M., Alghoul, M. A., Ibrahim, N. L. N., Shameri, M. A., & Elayeb, O. (2013). Research and development on aspects of daylighting fundamentals. *Renewable and Sustainable Energy Reviews, 21*, 494-505.

De Graaf, T., Dessouky, M., & Müller, H. F. (2014). Sustainable lighting of museum buildings. *Renewable Energy, 67*, 30-34.

Del Hoyo-Meléndez, J. M., Mecklenburg, M. F., & Doménech-Carbó, M. T. (2011). An evaluation of daylight distribution as an initial preventive conservation measure at two Smithsonian Institution Museums, Washington DC, USA. *Journal of Cultural Heritage, 12*(1), 54-64

Freewan, A. A. (2010). Maximizing the light shelf performance by interaction between light shelf geometries and a curved ceiling. *Energy Conversion and Management, 51*(8), 1600-1604.

Freewan, A. A., Shao, L., & Riffat, S. (2009). Interactions between louvers and ceiling geometry for maximum daylighting performance. *Renewable Energy, 34*(1), 223-232.

Ibrahim, N., & Zain-Ahmed, A. (2007). Daylight availability in an office interior due to various fenestration options. In *2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century, Crete island, Greece,* (Vo. 1, pp. 436-440).

Joarder, M. A. R., Ahmed, Z. N., Price, A. D., & Mourshed, M. (2009). A simulation assessment of the height of light shelves to enhance daylighting quality in tropical office buildings under overcast sky conditions in Dhaka, Bangladesh. In *Proceedings of the Eleventh International IBPSA Conference*, (pp.920-927), Glasgow, Scotland.

Kim, C. S., & Chung, S. J. (2011). Daylighting simulation as an architectural design process in museums installed with toplights. *Building and Environment, 46*(1), 210-222.

Maekawa, S., & Beltra,V. (2004). Climate controls for historic buildings. *The Getty Conservation Institute Newsletter, 19*(1), News in Conservation.

Rakha, T., & Nassar, K. (2011). Genetic algorithms for ceiling form optimization in response to daylight levels. *Renewable Energy, 36*(9), 2348-2356.

Shahriar, A. N. M., & Mohit, M. A. (2007). Estimating depth of daylight zone and PSALI for side lit office spaces using the CIE Standard General Sky. *Building and Environment, 42*(8), 2850-2859.

Thomson, G. (1990). *The Museum Environment*. The museum environment (2nd ed.) Butterworth-Heinemann, London: Elsevier.

Toledo, F. (2007). Museum passive buildings in warm, humid climate. In *Experts' Roundtable on Sustainable Climatic Management Strategies*, Tenerife, Spain, (pp. 1-26).

Wilson, M. (2006). Lighting in museums: Lighting interventions during the European demonstration project 'Energy efficiency and sustainability in retrofitted and new museum buildings' (NNES-1999-20). *International Journal of Sustainable Energy, 25*(3-4), 153-169.