The Influence on Daylight and Energy Consumption of Expanded Metal Mesh Applied on Building Façades

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Abstract. Expanded metal mesh has become widely used as a shading element in the façade of many buildings in recent years, and its energy saving performance has been evaluated in tropical/subtropical countries. However, expanded metal mesh reduces solar radiation while also reducing the natural daylight entering the building. This study's objective is to assess the impact of expanded metal mesh on building energy consumption and natural daylighting.
The daylight effects on visual comfort and energy consumption of an office building located in Tainan, Taiwan were studied via building simulation program DIVA. Parameters including window to wall ratios (WWR), perforation rate expanded metal mesh, and glazing of window glass were studied, and a daylight standard of LEED rating system was used for evaluation.
The results showed that when the office building with large WWR and less glazing, the expanded metal mesh performed a better energy saving effect. For an office building with 50% WWR, the laminated clear glass and expanded metal mesh with 21% perforation rate were suggested to be the best design solution for meeting the LEED daylight standard and the lowest energy consumption.

Keywords: Building Simulation, DIVA, LEED

1 Introduction

In recent years, expanded metal mesh has become widely adopted as a shading element in the façade of many buildings, and its energy saving ability has been evaluated in the building codes of countries like Singapore and Taiwan, which are located in tropical and subtropical regions. Expanded metal mesh is sheet metal that has been cut and stretched to form a regular pattern of metal mesh-like material. The 3D shape of the mesh reflects certain angles of solar radiation, while allowing some angles of solar radiation to pass through. These dual characteristics can promote the design flexibility of metal mesh on the façade and filter environmental elements that are not required.

However, since the shading device blocks solar radiation, it thus also reduces the daylighting in the building, so artificial lighting is required to achieve comfortable illumination, thus resulting in more energy consumption. Therefore, whether the shading device can effectively reduce the total energy consumption of a building is worthy of discussion.

Lin et al. [1] studied expanded metal mesh with different perforation rates and found that the practical transmittance was lower than the perforation rate, which meant that a higher shading performance could be evaluated. Alghoul et al. [2] demonstrated that the window-to-wall ratio and window orientation affect HVAC loading, and energy consumption increases with the window-to-wall ratio. Lau et al. (2016) showed that the energy consumption of office buildings is related to the external shading device and glazing type [3]. Meanwhile, Chi et al. (2017) studied different perforation rates, hole shapes, and hole distributions of perforated metal sheets. Their results revealed that the perforation rate is the main factor associated with daylight and energy consumption, and they found that using perforated metal mesh can increase the ratio of useful daylight illuminance (UDI) and reduce the solar radiation coming into buildings [4].

According to the above research, many factors will affect the energy consumption and daylighting of buildings, including window-to-wall ratio, shading device, and glazing type, but few studies have been carried out simultaneously with expanded metal mesh. This study aims to assess the impact of expanded metal mesh and architectural design factors on building energy consumption and natural daylighting.

2 Methods

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1.1 Case study subject

To evaluates the effects of different window-to-wall ratios (WWR), expanded metal mesh with different perforation rates, and different glazing types on building energy consumption and natural daylighting, we chose to simulate a typical medium-sized office building with a 40 m x 40 m 10-story RC structure (see Fig. 1).

We examined WWR at 30%, 50%, and 80% and the following three kinds of glazing: laminated clear glass, laminated blue glass, and Low-E glass (see Table 1). The transmittance scenarios of expanded metal mesh are shown in Table 1. Since expanded metal mesh has a 3D structure, its practical transmittance differs from its perforation rate. In this study, the simulated transmittance in direct irradiation is the actual ratio of ambient and indoor solar radiation achieved by experiment, and it is equal to the perforation rate in indirect time. Furthermore, expanded metal mesh is only installed outside the windows of the east and west sides of the office building.

1.2 Boundaries of simulation

In this study, we adopted DIVA for Rhino to simulate lighting and energy consumption throughout the year. DIVA for Rhino is an optimized daylighting and energy model plug-in for the Rhino modeler, which enabled us to carry out a series of environmental performance evaluations, including annual and individual time step glare analysis, LEED and CHPS daylighting compliance, and energy calculations. The lighting simulation was based on Radiance and Daysim, while the energy calculation was based on EnergyPlus.

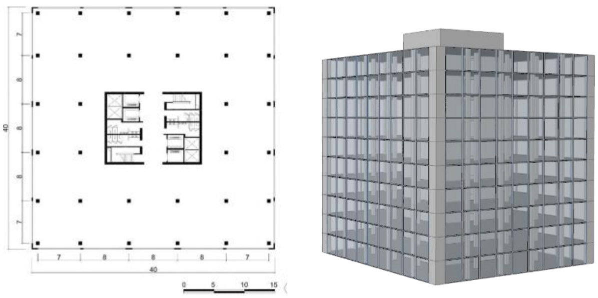
With regard to the simulation process, lighting simulation was first performed with DIVA to establish the lighting schedule (see Fig. 2), which was then imported into the DIVA-Archsim energy consumption simulator. In the simulation setting, the occupation time was from 8:00 to 18:00 on weekdays. The lighting switch was set with a Dimming with Occupancy On Off sensor option in the software lighting control system. After occupants left work, the lighting would not be switched on. In contrast, during office hours, the daylight harvesting system was used to offset the amount of electric lighting needed to properly light a space in order to reduce energy consumption. To accomplish this, a lighting control system that could dim or switch electric lighting in response to changing daylight availability was adopted. We set the standard target illuminance value required by office work as 500 lx at a height of 76 cm.

In the energy simulation setting, the main structure of the office building case was set as the reinforced concrete structure commonly found in Taiwan. Moreover, we determined the indoor heat load related setting according to the recommendations of Taiwan's Green Building Regulations, thus setting occupant density to 0.15 person/m^2, equipment density to 13.5W/m^2, air conditioning temperature set-point to 26˚C, and outdoor air flow rate to 8.5 L/(s·person).

1.3 Evaluation standard of simulation results

In this study, we used the daylight standard of Leadership in Energy and Environmental Design (LEED) for evaluation. Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) were adopted as two important measures for better understanding annual daylight availability and quality, as well as glare potential.

sDA was defined as the area in which illumination of the working plane reached 300 lx over 50% of the working time, and ASE was defined as the area in which illumination of the working plane reached over 1000 lx for more than 250 hours. Regarding office specifications, when the sDA value was 55%-74% and the ASE value was less than 10%, 2 points were given; when the sDA value was 75% or more, and the ASE value was less than 10%, 3 points were given.



(a) (b)

Fig. 1. (a) Standard floor plan configuration (b) Simulation model (WWR=80%)

Table 1. Glazing properties of three kinds of glass.

Glass type	Thickness	Visible transmittance	SHGC	U-value
	m	-	-	W/m^{2}K
Laminated clear glass	0.012	0.87	0.73	4.88
Laminated blue glass	0.012	0.60	0.53	4.88
Low-E glass	0.012	0.53	0.26	1.64

Table 2. Solar radiation transmittance of three kinds of expanded metal mesh.

Expanded metal mesh type	Perforation Rate (%)	Practical transmittance (%)			
		East		West	
		8:00–12:00	12:00–18:00	8:00–12:00	12:00–18:00
A	81	52	81	81	52
B	42	31	42	42	31
C	21	13	21	21	13

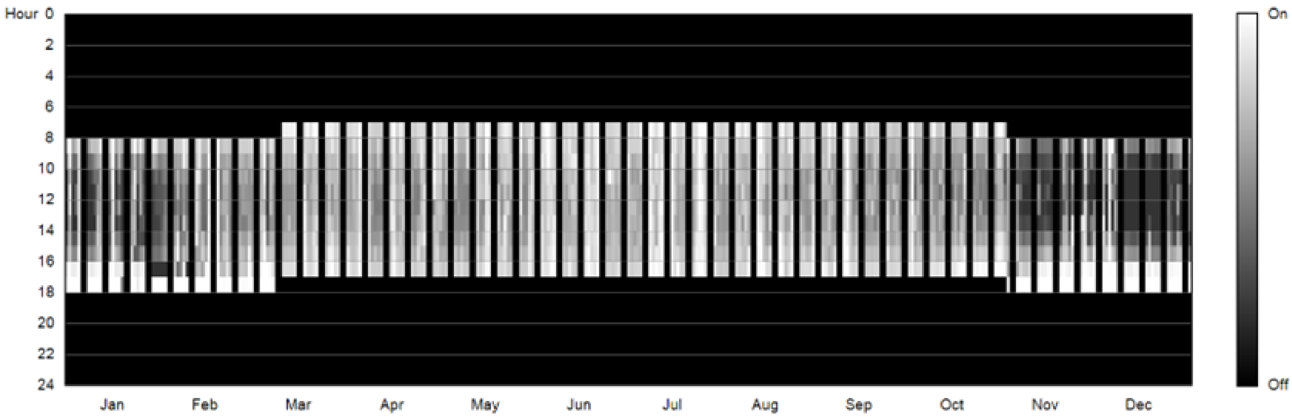


Fig. 2. The lighting schedule output by DIVA. (Scenario 28: WWR=30%, Perforation rate=21%, Laminated clear glass)

Table 3. The daylighting and energy consumption simulation results of 36 scenarios.

Scenario	WWR	Glazing Type	Expanded metal mesh	sDA	ASE	LEED Point	HVAC Energy	Lighting Energy	Total energy
S1	80%	Laminated clear glass	-	99%	39.0%	0	116.8	4.3	121.1
S2			A*	96%	18.9%	0	97.8	4.6	102.4
S3			B*	91%	16.1%	0	93.9	5.1	99.0
S4			C*	87%	13.5%	0	90.2	5.3	95.5
S5		Laminated blue glass	-	94%	34.7%	0	108.1	5.4	113.5
S6			A	84%	15.5%	0	92.8	6.1	98.9
S7			B	78%	14.1%	0	89.8	6.7	96.4
S8			C	67%	11.8%	0	87.0	7.4	94.4
S9		LowE glass	-	88%	33.5%	0	91.9	6.2	98.1
S10			A	76%	14.1%	0	83.1	7.4	90.5
S11			B	68%	13.3%	0	82.1	8.1	90.2
S12			C	58%	10.8%	0	81.2	9.2	90.4
S13	50%	Laminated clear glass	-	90%	30.1%	0	102.4	5.4	107.8
S14			A	79%	17.6%	0	91.8	5.9	97.7
S15			B	74%	9.7%	2	88.1	7.0	95.1
S16			C	65%	9.1%	2	86.1	7.6	93.7
S17		Laminated blue glass	-	77%	27.7%	0	97.7	7.6	105.3
S18			A	66%	14.7%	0	89.7	8.6	98.3
S19			B	60%	8.3%	2	86.8	10.6	97.3
S20			C	49%	8.1%	0	85.3	11.6	96.9
S21		LowE glass	-	69%	26.4%	0	86.5	9.6	96.1
S22			A	60%	13.0%	0	83.7	10.7	94.4
S23			B	52%	7.9%	0	82.2	12.9	95.1
S24			C	42%	8.0%	0	82.0	14.1	96.1
S25	30%	Laminated clear glass	-	61%	18.2%	0	94.8	10.2	105.0
S26			A	53%	10.8%	0	88.0	12.2	100.2
S27			B	48%	8.8%	0	87.8	14.8	102.6
S28			C	42%	6.7%	0	87.2	16.5	103.7
S29		Laminated blue glass	-	51%	16.5%	0	94.0	15.4	109.4
S30			A	43%	9.3%	0	88.6	18.1	106.8
S31			B	37%	7.5%	0	88.4	20.1	108.5
S32			C	30%	5.7%	0	87.8	21.4	109.3
S33		LowE glass	-	46%	16.2%	0	87.6	18.3	105.9
S34			A	38%	8.7%	0	85.4	20.7	106.1
S35			B	30%	6.3%	0	85.8	22.6	108.4
S36			C	25%	5.3%	0	85.8	23.6	109.4

A: Perforation rate=81%, Practical transmittance=52%, B: Perforation rate=42%, Practical transmittance=31%, B: Perforation rate=21%, Practical transmittance=13%

3 Results and discussion

In this study, 36 simulation scenarios were performed according to different WWR, glass properties, and perforation rates of expanded metal mesh. The lighting simulation results were evaluated according to the LEED lighting requirement. With regard to energy consumption, this study evaluated the performance of lighting and air conditioning energy consumption.

The summarized results are shown in Table 3. Nine scenarios without expanded metal mesh did not reach the daylighting standard, primarily because their illuminations exceeded the ASE standard. However, after expanded metal mesh was installed at the openings of the building, the ASE value was significantly reduced.

Our results showed that the expanded metal mesh effectively reduced direct and excessive sunlight. Nevertheless, if a Low-E glass with a low visible transmittance was used, the influence of the expanded metal mesh on preventing excessive light was also lowered. As shown in Table 4, in 36 scenarios, only S15, S16, and S19 conform with the LEED daylight standard. As shown in Figures 3, 4, and 5, the energy saving ratio of the scenario with 80% WWR was greater than the scenarios with 30% and 50% WWR. In other words, the greater the WWR, the greater the energy saving potential of expanded metal mesh and glazing. As for glazing type, the lower the SHGC value of the glass, the smaller the influence of the expanded metal mesh on HVAC energy saving.

In order to save air conditioning energy consumption, expanded metal mesh with a low perforation rate was used, which then increased lighting energy consumption due to insufficient illumination. In particular, when Low-E glass with a low solar heat gain coefficient was used, the expanded metal mesh resulted in a significant increase in lighting energy consumption. Taking S11 and S12 as examples, when the building was 80% WWR coupled with Low-E glass and expanded metal mesh with a 21% perforation rate, the energy consumption of the air conditioning could compare to the 42% perforation rate expanded metal mesh to reduce 1 EUI, but the lighting energy was increased 1.1 EUI. Overall, using C mesh consumed more energy than the B mesh.

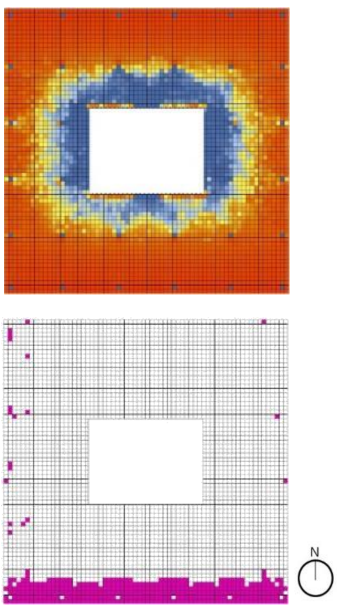
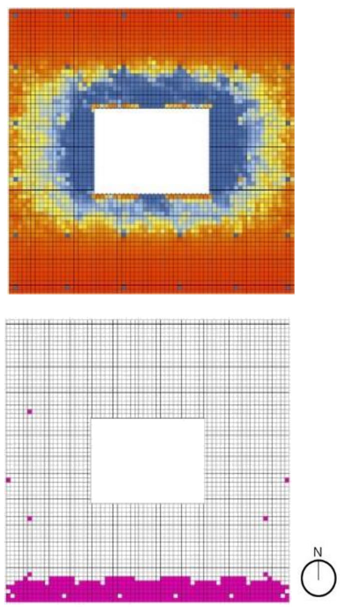
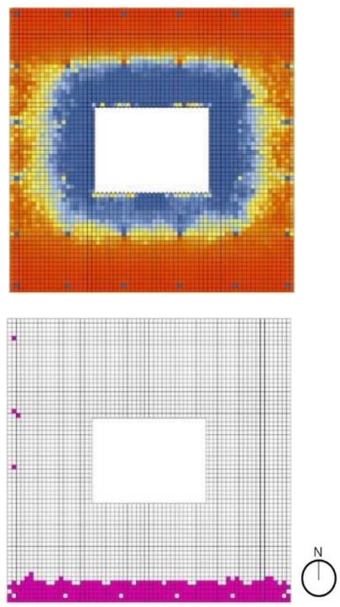
4 Conclusions

In this study, we adopted three factors commonly applied to building facade design to discuss the impact of lighting and air conditioning energy consumption. According to the results of our lighting simulations, only three scenarios conformed with the LEED daylight standard, and S16, which consisted of 50% WWR, laminated clear glass, and expanded metal mesh with a 21% perforation rate, displayed the greatest energy efficiency.

We also found WWR to be the main factor influencing the amount of daylight entering the building. Therefore, the greater the WWR, the greater the energy saving potential expanded metal mesh and glazing have.

With regard to the building energy consumption simulation, the lighting schedules output from DIVA with the daylight harvesting systems were input to the energy consumption simulation, enabling us to discuss the energy saving effect of daylight. The results demonstrated that the expanded metal mesh could effectively reduce direct and excessive sunlight. Nevertheless, if a Low-E glass with low visible transmittance is used, the influence of the expanded metal mesh on preventing excessive light would be reduced. When WWR is 80% and 50%, glazing with a higher visible transmittance can be used with expanded metal mesh to achieve better energy saving and daylighting quality. However, when the WWR was 30%, scenarios in which Low-E glass and expanded metal mesh were used at the same time are not recommended.

Table 4. Results of the three scenarios that reached the daylight standard

Scenario 15	Scenario 16	Scenario 19
sDA=74% 、ASE=9.7%	sDA=64% 、ASE=9.1%	sDA=60% 、ASE=8.3%
EUI=95.1	EUI=93.7	EUI=97.3
		

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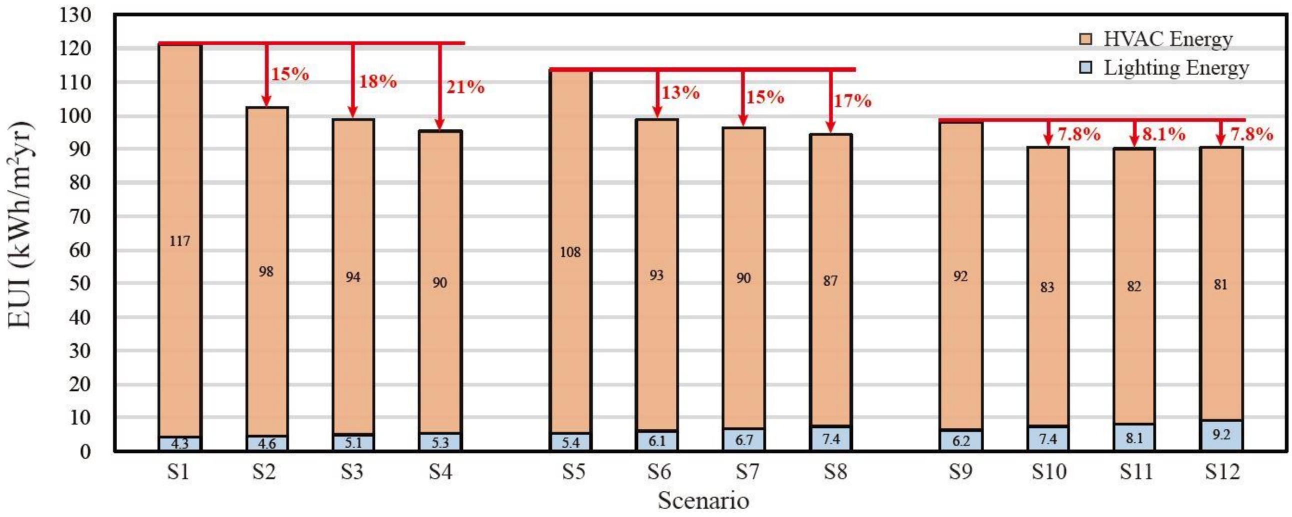

Fig. 3. Energy consumption throughout the whole year, WWR=80%.

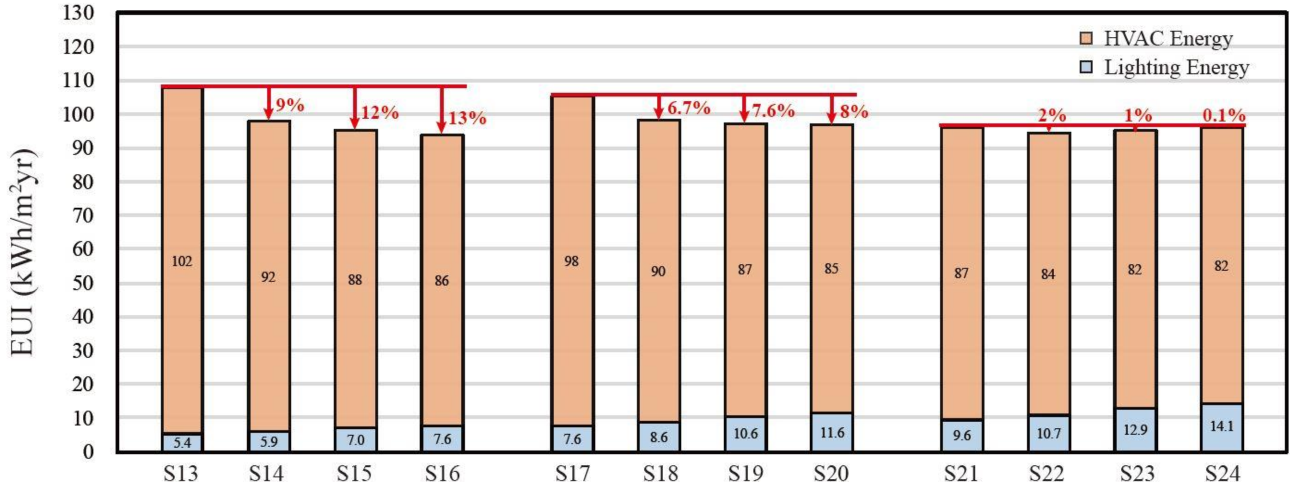

Fig. 4. Energy consumption throughout the whole year, WWR=50%.

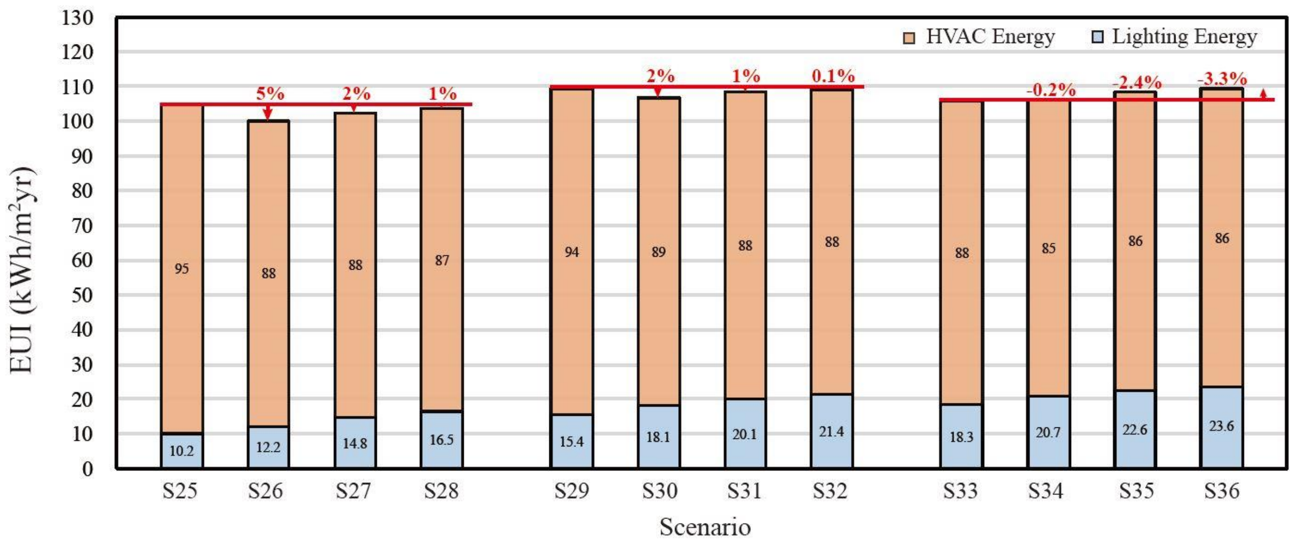

Fig. 5. Energy consumption throughout the whole year, WWR=30%.

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References

1. C.H. Lin, Y.S. Tsay, J.H. Yang, Y.F. Lin, *World Sustainable Built Environment Conference*, (2017)
2. S.K. Alghoul, H.G. Rijabo, M.E. Mashena. Building Engineering, **11**, 82-86, (2017).
3. D.A. Chi, D. Moreno, J. Navarro. Build. Environ., **125**, 383-400, (2017).
4. A.K.K. Lau, E. Salleh, C.H. Lim, M.Y. Sulaiman, *International Journal of Sustainable Built Environment*, **5**, 387-399, (2016).