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Thermal Performance & Glare Analysis of ETFE Roof Foil in Tropical Climate Condition

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Abstract

Glass construction can reflect heat and glare to the surrounding environment. Ethylene Tetrafluoroethylene (ETFE) is one of the low-cost solutions and lightweight materials used in construction compared to glass. The main issue of conventional glass is the high amount of heat absorbed into buildings in tropical climates. The purpose of this paper is to determine the thermal performance effects of ETFE foil installed on the roof of buildings. The field measurement consists of air-conditioned and non-air-conditioned environments, to compare the surface temperature of ETFE with glass in a tropical climate. Measurement of surface temperature will be recorded. This paper aims to explore the thermal properties of ETFE and its effectiveness in tropical climatic conditions compared to glass. Data were collected with on-site measurement in 1 Mont' Kiara Mall and Design Village Outlet Mall, Malaysia. Comparison analysis was done for the surface temperature of ETFE and glass with Aftab Alpha software to calculate daylight glare index (DGI). The result obtained from the analysis proved that ETFE roof is effective in both air-conditioned and non-air-conditioned environments. ETFE also performs better than glass in terms of heat reduction through the material. Luminance and glare analysis also showed that ETFE foil does not cause glare to the users. Therefore, the ETFE foil is suitable in tropical climate conditions to provide alternative shade better than glass in reducing the roof surface temperature.

Disciplinary: Sustainability and Green Technology, Energy Sciences, Architectural Science (Housing and Building), Civil Engineering & Technology.

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1 Introduction

World energy usage is increasing from time to time at the rate of 3.2%. From 1973-2006, the primary energy consumption went up by 89.5% due to developments. More than 40% of the total primary energy consumption comes from building energy usage (Hu et al., 2014). Options for renewable energy are needed to emphasize particularly in the building industry. Climate is an important issue in building design that needs to be solved by design or by the choice of building materials specifically in tropical climates. The important factors to determine the energy consumption of the building are heat and day-lighting. Daylighting can be optimized to light up the building interior to reduce the usage of artificial lighting which adds up to the total energy consumption. However, increasing the amount of daylighting into the interior spaces subsequently will increase the heat gain transfer into the building. To balance the interior thermal comfort, the high operational usage of air-conditioning systems is essential in maintaining the equilibrium. Therefore, it will increase energy consumption in the long run.

2 Literature Review

Glass construction can allow sufficient daylighting to the internal space. However, it will also reflect heat and glare to the surrounding environment. Unfortunately, it will increase the urban heat gain due to the rise of ambient temperature built up if not properly controlled during the design stage. These will cause the urban heat island effect which in turn contributes to global warming. At least 20-40% of the total energy consumption comes from building glass construction (Pérez-Lombard, Ortiz, & Pout, 2008). Apart from that, conventional construction methods with glass are not flexible in terms of design and their heavy weight. The aesthetical limitation leads to an increase in development and construction costs (Capezzuto, 2016). To overcome this issue, Ethylene Tetrafluoroethylene (ETFE) is one of the alternative solutions to instill low-cost and lightweight material in construction compared to glass (Lamnatou et al., 2018). However, the main problem is a high amount of heat absorbed into the building in tropical climates that leads to the over usage of air conditioning system. The other problems encountered are the difficulty in controlling daylighting and glare for the particular use of internal space. High intensity of daylighting and glare could affect a person's visual perspective, thus affecting their comfort level. ETFE foils features allow 94-97% of light transmission and have less reflected light and heat to the atmosphere (Hu et al., 2017; Hu et al., 2017a) The usage of ETFE in construction reduces heat transfer from outdoor to indoor spaces through air cushion between foils which in turn reduced the energy consumption to cool the interior space.

3 Method

In this paper, the heat and light transmittance performances of ETFE are measured in two selected case study buildings: Case Study A, 1 Mont' Kiara Mall in Kuala Lumpur, and Case Study B, Design Village Outlet Mall in Penang. Case Study A is an enclosed air-conditioned building whereas Case Study B is in an opened non-air-conditioned environment. An infrared Thermometer (Figure 3) was used to measure the surface temperature of ETFE and glass roofs. Readings were obtained from 1500mm above finished floor level. A lux meter (Figure 3) was used to measure luminance under the roof (Dahlan et al., 2009). Measurements were taken instantaneously with two-hour intervals between 09:00 hours and 17:00 hours for three days (26, 27, 28 April for Case Study A and 4, 5, 11 May 2019 for Case Study B) under partly cloudy sky condition. In addition, HDR photos were taken with Nikon D5100 (Figure 4) and the images were analysed with ‘Aftab Alpha’ software to determine the degree of perceived glare. These photos were developed into false-colour picture rendering and use ‘Evalglare’ interface to assess glare as an alternative method.

3.1 Case Study A: 1 Mont Kiara Mall, Kuala Lumpur, Malaysia

The roof structure in the atrium of the mall uses a mixture of both ETFE foil and glass. The ETFE roof is made of ‘Double Layer Clear with Dot Frit Pattern that covers 6.3% printed on the underside of outer layer’ and the glass used is a 33.52mm thick Double Glazing Glass (Figure 1).

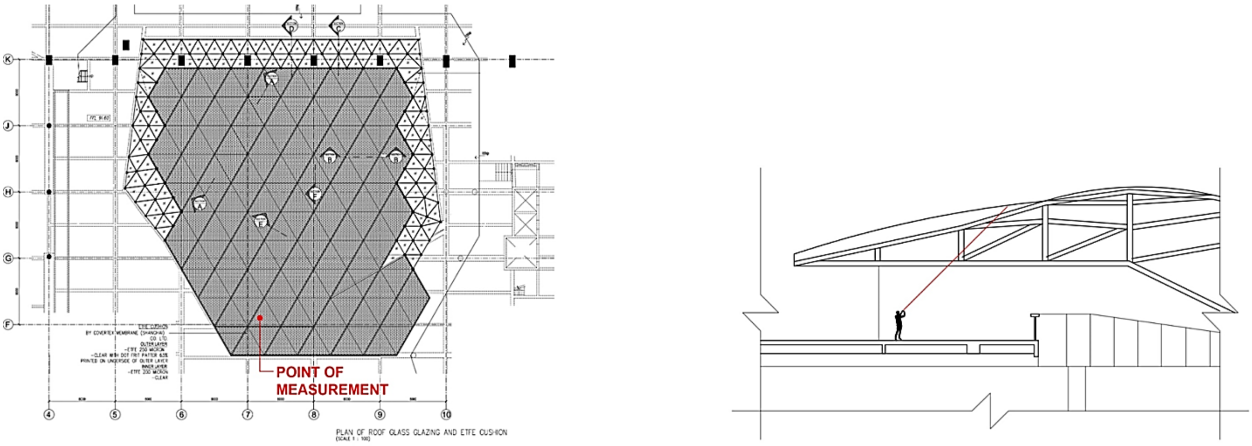

Figure 1: 1 Mont Kiara Mall Kuala Lumpur Point of Measurement Plan & Section for Point of Measurement.

3.2 Case Study B (Design Village Outlet Mall, Penang, Malaysia)

The roof structure for this building is in between the retail shop. This case study uses an ETFE membrane. The structure is within a non-air-conditioned environment which opposes the roof in 1 Mont’ Kiara Mall which is totally in an air-conditioned environment. The ETFE foil used for the roof structure is ‘Double Layered Tinted Blue Film with Silver Dot Printing’ (Figure 2).

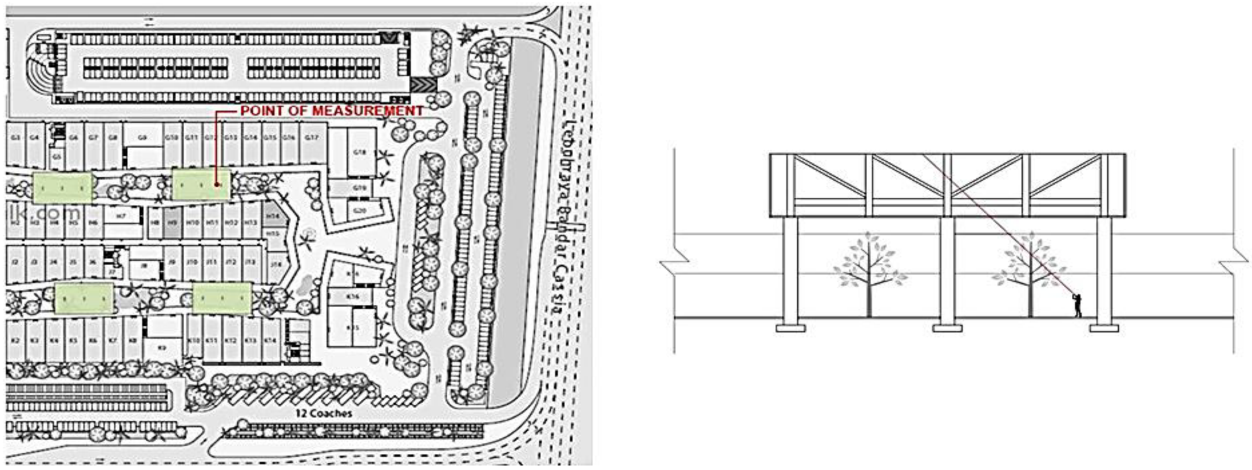

Figure 2: Design Village Point of Measurement Plan in Penang & Design Village Section for Point of Measurement in Penang.

Figure 3: Infrared Thermometer & Lux Meter.

Figure 4: Nikon D5100 for taking photos.

4 Result and Discussion

The findings are presented in three categories with a comparative study between ETFE foils, a comparative study between ETFE and glass, and finally the analysis of luminance and glare. From the data collected, Table 1 indicated that the average outdoor temperatures were estimated at least 32°C. The mean outdoor temperatures were based on 1-hour intervals started from 09:00 hours to 17:00 hours respectively. The highest outdoor temperature recorded was at least a maximum reading of 33.5°C at 13:00 hours for case study A. For case study B, the highest outdoor temperature was recorded also at 13:00 hours with a reading reached a maximum of 32.0°C. During this time, the ETFE surface temperature for case study A recorded at least 36.7°C while it is estimated at 36.0°C for case study B. The percentage difference for outdoor temperature was at least 1.9% and is based on climate conditions and locations of that time. Referring to the Meteorological Department Penang (2009), the outdoor temperature of Kuala Lumpur in April was higher than Penang in May 2019 that affects the overall readings. From Table 1 and Figure 5, the highlighted readings indicated when exposed to an outdoor temperature at an average reading of 32.0°C, the ETFE foils mean surface temperatures performed at least 36.0°C for both cases (case studies A & B).

Table 1: Mean ETFE surface temperatures on Case Studies A & B.

Time	Case Study A (1 Mont Kiara)			Case Study B (Design Village)		
	Mean Outdoor Temp. (°C)	Mean ETFE Surface Temp. (°C)	Difference (%)	Mean Outdoor Temp. (°C)	Mean ETFE Surface Temp.(°C)	Difference (%)
09.00 hours	30.7	31.2	1.39	29.5	31.0	4.80
11.00 hours	31.8	34.1	6.65	30.5	33.8	9.61
13.00 hours	33.5	36.7	8.64	32.0	36.0	11.12
15.00 hours	32.5	36.0	9.55	31.3	35.9	12.81
17.00 hours	31.7	35.0	9.51	30.9	35.6	13.20
Mean	32.0	34.6	7.31	30.8	34.5	10.47

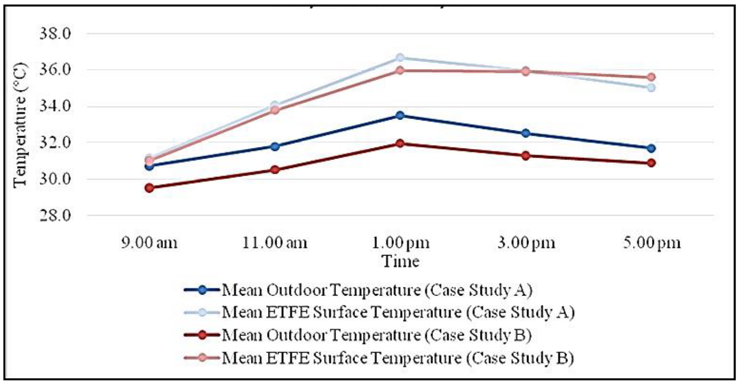

Figure 5: Mean outdoor temperature and mean ETFE surface temperatures on Case Studies A & B.

4.1 Surface Temperature of ETFE & Glass Material

When the ETFE foils were set to compare with glass material in Table 2, it showed that the ETFE foils roofing performed better with mean surface temperature readings lower by 1.9°C or 5% reduction highlighted at 15:00 hours. At this point, the ETFE roofing foils were at 36.0°C while the glass roofing was at 37.9°C (Table 2), at 15:00 hours. If the maximum readings were taken into consideration at 13:00 hours similar to Table 1, the ETFE roofing foils still performed with a reduction of almost 5%. It can be concluded that the ETFE roofing foils perform better in terms of mean surface temperature. Apart from that, the comparison of ETFE and glass roofing was based only on case study A due limited situation of unavailability of glass material at Design Village Penang. The result in Table 2 showed that the surface temperature on the glass is much higher than the ETFE and it is illustrated in Figure 6. There is a mean average difference of 5% or 1.9°C highlighted in Table 2 as an example of the comparison efficiency. Therefore the comparison of surface temperature with the use of ETFE compared to glass agreed with Cremers & Marx (2016, 2017) that the air cushion between ETFE foil significantly reduces the heat transferred from the outer layer to the inner layer sheet causing ignition of thermal lag. Both ETFE foil and glass had two layers; however, the surface temperature measured on ETFE was relatively lower than the glass roof material. This study confirms that double-layered ETFE foil roofing performs better in heat reduction than double-glazed glass roofing.

Table 2: Case Study a Mean Surface Temperatures.

Time	Mean ETFE Surface Temp. (°C)	Mean Glass Surface Temp. (°C)	Temperature Difference(°C) /Percentage of Difference (%)
09.00 hours	31.2	33.6	2.47/7.1
11.00 hours	34.1	37.0	2.9/7.8
13.00 hours	36.7	38.5	1.8/ 4.67
15.00 hours	**36.0**	**37.9**	**1.9/5**
17.00 hours	35.0	37.4	2.4/6.4
Mean	34.6	36.6	2/5.5

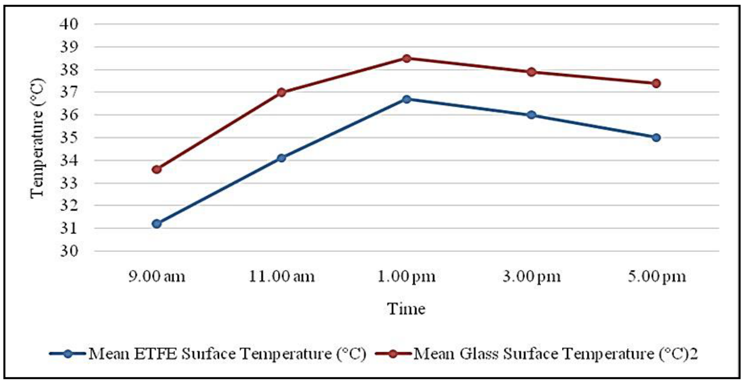

Figure 6: Mean surface temperature of ETFE & glass roofing.

4.2 Luminance Analysis

In this part, the luminance analysis based on cased studies A & B was carried out. Figure 7 showed the overall luminance taken from 1 Mont Kiara Kuala Lumpur (case study A). From the figure, it showed the original photo and false-coloured picture rendering captured at 11.00 hours for comparison purposes. The results indicated a low brightness contrast that would enhance the visual surrounding of the roof. The diffused light caused an interesting visual luminance under the ETFE roof. The highest luminance ever recorded was at 15:00 hours under partly cloudy sky condition with a measured reading of 7366.7 lux (Table 3). However, for case study B in Design Village Penang, the highest luminance was recorded at 17:00 hours with reading approximately 6500lux less by an average of 10%. Both luminance conditions for case studies A and B fall under 'more than the recommended luminance' in Malaysian Standard (MS1525, 2014). The results obtained from both case studies field measurements showed that Case Study A (1 Mont Kiara Kuala Lumpur) had a higher mean value of luminance under roof with 7033.3 lux compared to Case Study B (design Village Penang) with 6100 lux. There is an estimated 13.27% difference in terms of luminance values for both case studies. The percentage differences are due to different measurement points. For Case Study A, it is nearer to the ETFE roof (Figure 1) whereas for Case Study B, the measurement was done further away from the ETFE roof (Figure 2) due to limitation of space, height, and volume to occupy similar reading conditions.

4.3 Glare Analysis

Finally, for glare analysis, it was carried in line with the luminance analysis measurement for both case studies. The daylight glare index (DGI) was generated using 'Evalglare' an interface in 'Aftab Alpha' software. It showed that the reading of case study A (1 Mont Kiara Kuala Lumpur) falls under the category of 'just perceptible' with reading marked at 16 DGI (Table 4). For case study B (Design Village Penang), the

DGI valued at 12 is also considered to fall under the 'perceptible' degree of perceived glare. Hence, from these obtained field measurements, the amount of luminance and glare under the ETFE roof for both cases were tolerable by building occupants and does not create issues when exposed too long (Adel et al., 2009). Apart from that, it can be concluded that the thermal performance of the ETFE roof can enhance the visual appearance in diffused light and does not cause glare for the user to perform daily tasks**.** This will give an insight to the developer or designers in choosing ETFE material over glass for future projects.

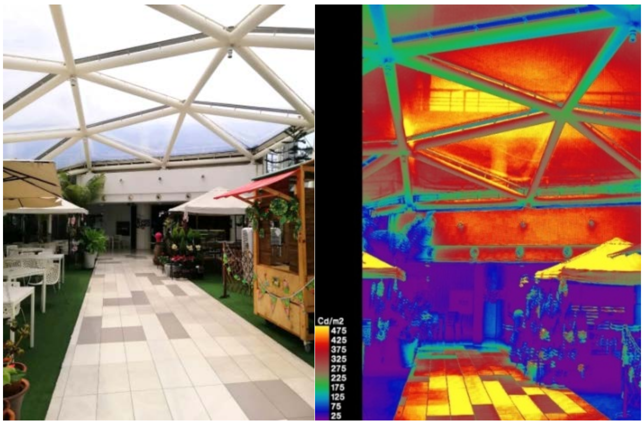

Figure 7: 1 Mont Kiara ETFE roofing & DGI Image.

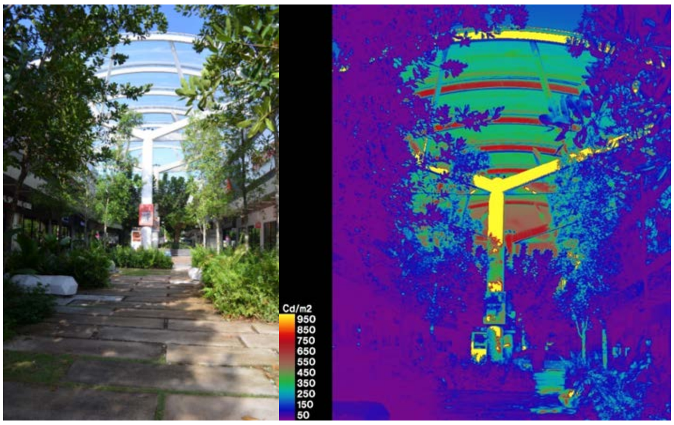

Figure 8: Design Village Penang ETFE Roofing & DGI Image.

Table 3: Mean Luminance on Case Study A & Case Study B Roofing.

Time	Case Study A Mean Lighting Under Roof (lux)	Case Study B Mean Lighting Under Roof (lux)	Percentage of Difference (%)
09.00 hours	6500.0	5766.7	11.28
11.00 hours	6766.7	5833.3	13.79
13.00 hours	7266.7	6300.0	13.30
15.00 hours	7366.7	6100.0	17.19
17.00 hours	7266.7	6500.0	10.55
Mean	7033.3	6100.0	13.27

Table 4: Degree of Perceived Glare by Building Occupants.

Degree of Perceived Glare	GI	DGI
Just perceptible	10	16
Just acceptable	16	20
Borderline Comfort and Discomfort	18.5	22
Just uncomfortable	22	24
Just intolerable	28	28

5 Conclusion

From this research paper, the ETFE roofing foil is suitable to be used in tropical climatic conditions as part of a roofing structure that provides shade and daylighting. From the findings, the ETFE foil performs better than double glazing glass in reducing the roof surface temperature. Hence, the reduction of these surface temperatures would eventually have the potential to reduce building energy usage, especially for the indoor cooling load. In the future, more accurate data could be obtained with multiple measurement points and parameters for best comparisons.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

7 Acknowledgment

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