THE IMPACT OF AIR GAPS ON THE PERFORMANCE OF REFLECTIVE INSULATIONS

Lim Chin Haw[1*] and Chan Seong Aun[2]

[1]Solar Energy Research Institute (SERI), Level G, Research Complex, Universiti Kebangsaan Malaysia 43600 Bangi, Selangor, Malaysia.

[2]Greenbuildingindex Sdn Bhd, A-12-13A, Menara UOA Bangsar, No. 5, Jalan Bangsar Utama 1, 59000 Kuala Lumpur, Malaysia.

* Corresponding author:
chinhaw.lim@ukm.edu.my

ABSTRACT

Solar heat gain is the primary issue for cooling energy which accounts for the highest energy consumption in building particularly in hot and humid climate like Malaysia. Approximately 93% of the solar heat gain through a roof is by radiation compared to conduction and convection methods. One of the most effective passive strategies to reduce radiative heat transfer through a roof is by using reflective insulation. Generally, reflective insulations are insulation materials that have low emissivity which ranges from 0.03 to 0.04 with high reflectance values. The assembly of a reflective insulation is characterized by an enclosed air gaps adjacent to low-emittance surfaces like aluminum foil. The performance of reflective insulation is commonly evaluated in accordance to ASTM C518 Standard using Heat Flow Meter. The objective of this paper is to analyze the performance of four different types of reflective insulations with various enclosed air gaps namely the big bubble aluminum foil, small bubble foil, woven foil and metalized foil. Based on the measurement and analysis, it was discovered that the big bubble foil with 50mm top air gap and 75mm bottom air gap has the highest R-value of 2.38.

Keywords: *Reflective insulation, solar heat gain, radiation, emissivity, R-value.*

1. INTRODUCTION

One of the most effective passive strategies to reduce cooling energy consumption in a building is by using thermal insulation. Generally, high solar radiation in tropical countries is being absorbed by buildings external envelope which causes high amount of solar heat gain emitted inside the building that will increase the energy consumption due to higher cooling load (Escudero et al., 2013). Therefore, for this reason, decreasing the solar heat gain became a big challenge especially in designing green and low energy buildings (Filho and Oliveira Santos 2014).

The insulation materials or products that are used in tropical buildings should have high thermal resistance. Hence, characterization of the insulation properties have to be taken into consideration before deciding its installation assemblies on building components (Hauser et al., 2013). The insulation materials and assemblies are commonly found on roofs, façade, walls and floors components. For tropical countries with high intensity of infra-red solar radiation, it was discovered that the most effective method to reduce the solar heat gain and energy consumption is by installing the insulation on the roof component (Hernández-Pérez et al. 2014). Researchers have also discovered that reflective insulation installation on the roof was able to reduce heat flux by 26% to 50% and cooling load by 6% to 16% (Lee S.W. et al., 2016).

Therefore, most of the studies found that building insulations were conducted on roofs as compared to other building components like walls, façade and floors components. Based on previous research, large size roof of buildings in hot climate especially non-residential buildings such as airports, shopping malls, industrial factories and exhibition halls with proper thermal insulation could able to reduce up to 50% of thermal heat gain inside the buildings (Hernández-Pérez et al. 2014). This high percentage of thermal heat gain is normally due to high solar radiation exposure of the large roof area as compared to the other building components such as external walls and façade. Researchers have also discovered that the internal rate of return (IRR) for installation of reflective insulation on a typical hypermarket is approximately 15.83% (Lee S.W. et al., 2017).

There are mainly two major categories of building insulations namely the mass or bulk insulation and reflective insulations. Studies have found that heat transfer by radiation is the primary mode of heat transfer in buildings envelope in hot climate as compared to other heat transfer methods like conduction and convection (Chang, P.C. et al., 2008). Hence, reflective insulation is considered the most effective method in reducing radiant heat transfer.

The thermal performance of reflective insulation is highly dependent of the thermal properties of its materials and assemblies as building components (Al-Homoud 2005). The key parameters that influence the performance of reflective insulations are air gap, emissivity and surface temperature. There are several characterization methods that can be used to determine the thermal performance of the insulation assemblies for reflective insulations.

The standard thermal characterization methods to evaluate the performance of reflective insulation are the guarded hot-plate apparatus test method under ASTM C177, the heat flow meter apparatus test method under ASTM C518 and the hot-box apparatus test method under ASTM C1363. The heat flow meter test method is commonly accepted as a method to characterize the reflective insulation layer itself whereas the guarded hot-box test method is used to determine the total thermal resistance of a building component or assemblies including radiant barrier (Escudero et al. 2013). In this study, the heat flow meter characterization method is used to determine the R-Value of different thermal insulation assemblies. Researchers have evaluated a double roof prototype insulation assemblies using reflective insulations and it was discovered that the reflective insulations was effective in reducing the radiative heat transfer from the roof to the ceiling (Chang P.C. et al., 2008).

In order to obtain the value of the thermal resistance of different reflective insulations used in building insulation, the heat flow meter apparatus and the guarded hot box method were extensively used by researchers (Escudero et al. 2013). The two different configurations have been tested and compared with simple analytical model according to ISO6946 standards using CFD analysis. It was found that both of the experimental lab methods were suitable for characterization of reflective insulations.

A comparative analytical study of the thermal performance for a large area of metal roof type building was conducted for a building in the tropical climate. Based on heat transfer modelling through the roof of an exhibition hall in Brazil, it was found that the coating of the roof for this type of building could reduce the energy consumption by reducing the solar heat gain into the building (Filho and Oliveira Santos 2014).

Researchers also have studied the effect of energy saving of reflective insulation on exterior building envelopes based on different weather conditions (Guo et al. 2012). The study was carried out under both summer and winter weather conditions. In the experiment, reflective insulation materials was applied to the exterior envelopes as a coating layer. The experimental was carried out on an actual building room conditions to cater for different rooms orientations. The indoor test results revealed that the insulation coating performs better than the non-insulation coating with temperature different of 0.73°C with monthly energy saving of 5.8 kWh/m^2.

In this study, the thermal characteristics performance of reflective insulation materials has been tested experimentally using Heat Flow Meter (HFM) method in accordance to ASTM C518 test method. Different types of reflective insulation materials were used namely: big bubble aluminum foil, small bubble aluminum foil and woven foil with variable air gaps.

2. TYPES OF ROOF REFLECTIVE INSULATION

The reflective insulation product is still a fairly new product that was just introduced in the building market lately as a highly promising new type of thermal insulation material. Due to the commercial market claim of its high performance, it has triggered numerous ongoing debate on this issue particularly in comparison with mass insulation like rockwool (Tenpierik and Hasselaar 2013). Both types of reflective insulation and mass insulation have different functions and applications. The mass insulation such as rockwool primarily reduce heat transfer by trapping air. Hence, it mainly reduces the convective heat transfer and it is not as effective in reducing radiant heat transfer which is often a primary mode of heat transfer in a building envelope. On the other hand, the reflective insulation uses layers of aluminum foil to trap air due to its low emissivity surfaces and it is very effective in reducing radiative heat transfer as much as 97% (Tenpierik and Hasselaar 2013)

(RIMA International 2014). Typically the bubble foil construction consists of air bubbles encapsulated in between two sides of aluminum foils with low emissivity values. The material or product itself only has very low thermal resistance. However, if the product is installed with enclosed air gaps facing its reflective surfaces, it has significant thermal resistance values as shown in Figure 1.

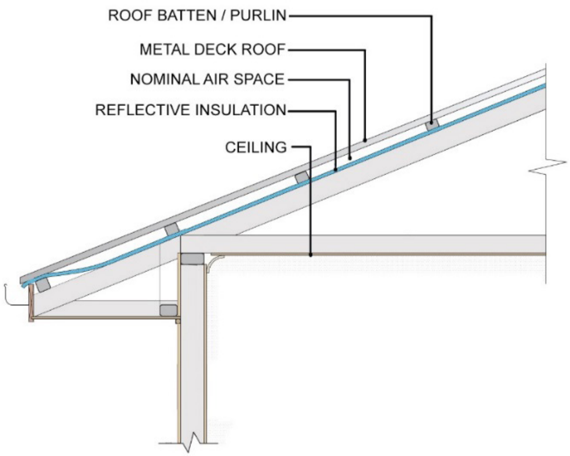


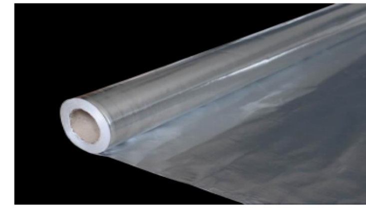
Figure 1: Example of roof construction with reflective foil insulation

The main objective of this research to determine the performance or the thermal resistance (R-value) of four different types of reflective insulations namely the big bubble aluminum foil, small bubble foil, woven foil and metalized foil with different configurations of air gaps. Figure 2 shows the types of reflective insulations.

(a)

(b)

(c)



(d)

Figure 2: (a) Small bubble foil; (b) Big bubble foil; (c) Woven Foil; (d) Metalized foil

3. METHODOLOGY

The application of heat flow meter for thermal characterization on reflective insulation has been considered as one of the most reliable method in determining the performance of reflective insulation (Saber 2012). In this characterization study, LaserComp Heat Flow Meter model FOX 600 was used to determine the thermal conductivity and subsequently for R-value calculation as shown in Figure 3.

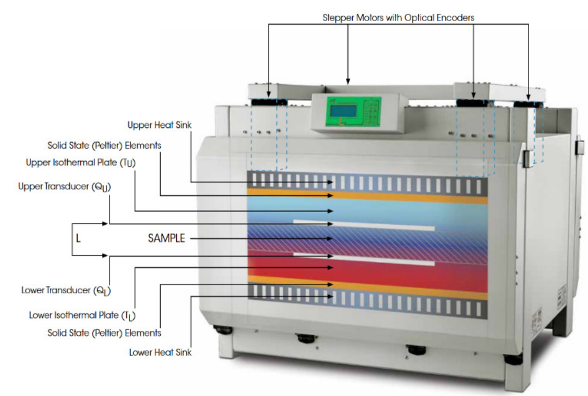


Figure 3: LaserComp Model FOX 600 Heat Flow Meter [11]

The heat flow meter is a steady state technique for measurement of thermal conductivity and it is also commonly used by researchers and industry professionals to determine the R-VALUE of insulation materials. In order to measure the thermal conductivity of the assemblies of the reflective insulation, the heat flow meter, a sample is positioned in between two temperature controlled plates.

These plates establish the temperature difference (ΔT) across the sample. The sample thickness (L) can be manually keyed into the heat flow meter control panel or allowing the heat flow meter to automatically measure the thickness of the sample. The thickness of the sample is vital because it is used in the calculation of the R-value. The heat flux (Q/A) from the steady –state heat transfer through the sample is measured by two proprietary thin film heat flux transducers covering a large area of upper and lower sample surfaces in order to ensure the exact measurement of the heat flow. The average heat flux is used to calculate the thermal conductivity (λ) and thermal resistance (R), according to Fourier's Law:

$$\lambda = \frac{Q}{A} \times \frac{L}{\Delta T} \qquad \text{W/mK} \qquad (1)$$

$$R = \frac{1}{\lambda} L \qquad \text{m2K/W} \qquad (2)$$

In order to measure the assembly of the reflective insulation with the air gaps, a timber frame was used to create air gaps for top and bottom of the aluminum foil as shown in Figure 4.

Figure 4: Timber frames are used to create top and bottom air gaps for bubble foil for heat flow measurement

Subsequently, the temperature of the top plate of the heat flow meter was set to 35°C and the bottom plate to 20°C respectively. The temperature settings are based on the requirement by MS 2095:2014 Radiant barrier and reflective insulation building materials – Specification (Frist revision). The heat flow direction of the sample assembly was based on downwards flow direction as shown in Figure 5. The sample size was 600mm x 600mm with different configurations of air gaps that ranges from 25mm, 50mm, 75mm, 100mm, 125mm and 150mm.

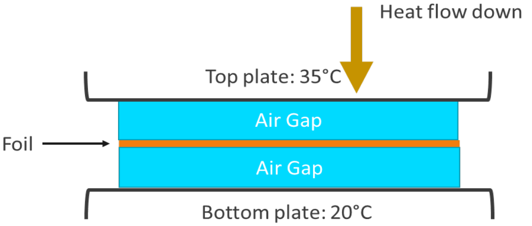


Figure 5: Diagram of the heat flow meter top and bottom plate temperature settings, air gaps and heat flow downwards direction

All the heat flow meter measurement settings for small bubble foil, big bubble foil, woven foil and metalized foil with different air gaps configurations are as shown in Table 1. There were total of 14 different types of configurations for this study.

Table 1: Top and Bottom Plate Temperature Settings and different Air Gaps Configurations for Heat Flow Meter Measurement

Top plate temperature (°C)	Bottom plate temperature (°C)	Top air gap (mm)	Bottom air gap (mm)
35	20	25	25
35	20	25	50
35	20	25	75
35	20	25	100
35	20	25	125
35	20	50	25
35	20	50	50
35	20	50	75
35	20	50	100
35	20	50	125
35	20	75	25
35	20	75	50
35	20	75	75
35	20	75	100

4. RESULTS AND DISCUSSION

Based on the results of the heat flow meter measurement and the R-value calculations for big bubble foil, the optimum R-value of 2.38 m2K/W was achieved with top air gap of 50mm and bottom air gap of 75mm as shown in Figure 6. The analysis also revealed that as the air gap exceeded 75mm, the R-value began to decrease. The effect of bigger air gaps influencing the R-value could be due to the occurrence of convective heat transfer or heat lost in the air gaps that caused both top and bottom air gap as ineffective insulation layer. In order for the air gaps to act as an effective insulation layer, it needs to avoid any convective heat transfer to occur.

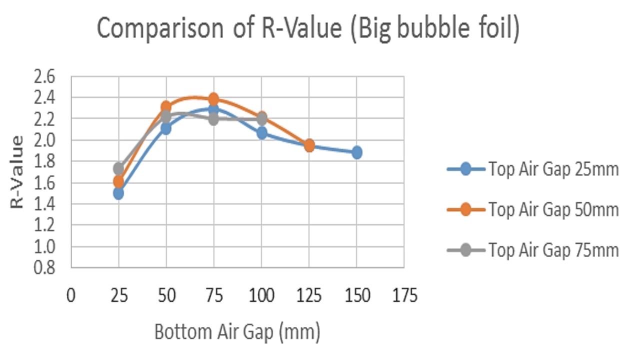


Figure 6: Thermal resistance or R-value (m2K/W) for Big Bubble Foil with different air gaps configurations

Figure 7 shows the R-value of the Woven foil with different air gaps configurations. Based on the analysis, the highest R-value for Woven foil was 2.16 m2K/W with 50mm for top air gap and 50mm for bottom air gap. The analysis also showed that the R-value for the Woven foil decreases as the air gaps exceeded 75mm.

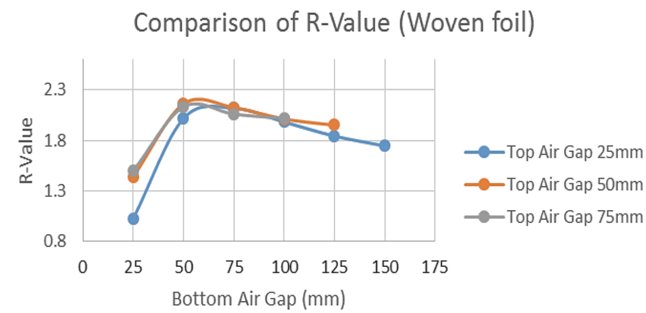


Figure 7: Thermal resistance or R-value (m2K/W) for Woven foil with different air gaps configurations

Figure 8 shows the R-value results for Small bubble foil with different air gaps. The study found that the highest R-value for Small bubble foil was 2.32 m2K/W with top air gap of 50mm and bottom air gap of 50mm. The analysis also shows that the R-value decreases when the air gap exceeded 75mm.

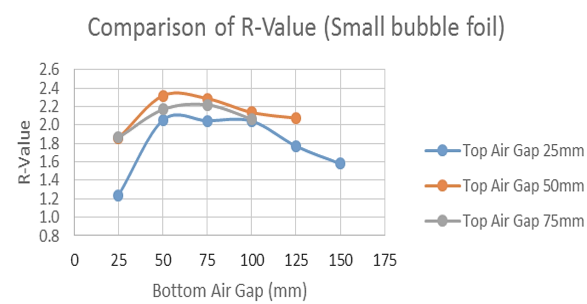


Figure 8: Thermal resistance or R-value (m2K/W) for Small bubble foil with different air gaps configurations

Figure. 9 shows the R-value of the metalized foil (MP2) with different air gaps configurations. Based on the measurement re sults, the optimum air gap configuration for MP2 is 0.63 m2K/W with 75mm for top air gap and 75mm for bottom air gap. The thermal performance of the MP2 was the lowest compared to the big bubble foil, small bubble foil and woven foil.

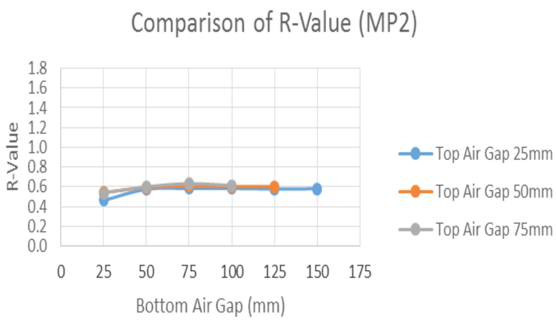


Figure 9: Thermal resistance or R-value (m2K/W) for metalized foil (MP2) with different air gaps configurations

Table 2 shows the summary of the performance of all the 4 types of reflective insulation with optimum air gaps configurations. Based on the analysis, the top air gap of 50mm was the optimum air gap for the three types of reflective insulations and the bottom air gap was 50mm and 75mm. Any lesser or bigger air gap does not assist in increasing the R-value of the reflective insulation.

Table 2: Summary of the performance of all the 3 types of reflective insulation with optimum air gaps.

Types of Reflective insulation	Optimum R-value (m^2K/W)	Optimum air gaps	
		Top air gap (mm)	Bottom air gap (mm)
Big bubble foil	2.38	50	75
Small bubble foil	2.32	50	50
Woven foil	2.16	50	50
Metalized foil	0.63	75	75

5. CONCLUSIONS

Based on this study, it was found that reflective insulation and radiant barrier were effective insulation to reduce the solar radiant heat gain with downwards heat flow from the roof. The test results showed that the R-value for the four types of reflective insulation were namely big bubble foil, small bubble foil, woven foil and metalized foil ranges from 0.63 m2K/W to 2.38 m2K/W. The highest R-value was the big bubble foil with R-value of 2.38 m2K/W. The research also discovered that when the air gaps for top and bottom of the reflective insulation exceeded 75mm, the R-value decreases. This effect was also encountered by other researchers in the studies on reflective insulation using heat flow meter method and it was generally due to the convective heat transfer that occurred when both the top and bottom air gaps of the reflective insulation were larger than 75mm.

ACKNOWLEDGEMENT

The authors would like to extend their gratitude towards the Arus Perdana Grant AP-2017-006/1 of Universiti Kebangsaan Malaysia and Greenbuildingindex Sdn Bhd for the financial assistance and without which this research would not have been possible.

REFERENCES

Al-Homoud, Mohammad S. 2005. “Performance Characteristics and Practical Applications of Common Building Thermal Insulation Materials.” *Building and Environment* 40(3):353–66.

Chang, Pei Chi, Che Ming Chiang, and Chi Ming Lai. 2008. “Development and Preliminary Evaluation of Double Roof Prototypes Incorporating RBS (Radiant Barrier System).” *Energy and Buildings* 40(2):140–47.

Escudero, C., K. Martin, A. Erkoreka, I. Flores, and J. M. Sala. 2013. “Experimental Thermal Characterization of Radiant Barriers for Building Insulation.” *Energy and Buildings*.

Filho, J. P. Brito and T. V Oliveira Santos. 2014. “Thermal Analysis of Roofs with Thermal Insulation Layer and Reflective Coatings in Subtropical and Equatorial Climate Regions in Brazil.” *Energy and Buildings* 84:466–74.

Guo, W., X. Qiao, Y. Huang, M. Fang, and X. Han. 2012. “Study on Energy Saving Effect of Heat-Reflective Insulation Coating on Envelopes in the Hot Summer and Cold Winter Zone.” *Energy and Buildings*.

Hauser, Gerd, Matthias Kersken, Herbert Sinnesbichler, and Almuth Schade. 2013. “Experimental and Numerical Investigations for Comparing the Thermal Performance of Infrared Reflecting Insulation and of Mineral Wool.” *Energy and Buildings*.

Hernández-Pérez, I. et al. 2014. “Thermal Performance of Reflective Materials Applied to Exterior Building Components - A Review.” *Energy and Buildings*.

Lee, S. W., C. H. Lim, and E. @. I. B. Salleh. 2016. “Reflective Thermal Insulation Systems in Building: A Review on Radiant Barrier and

Reflective Insulation." *Renewable and Sustainable Energy Reviews* 65.
Lee, Sau Wai, Chin Haw Lim, Seong Aun Chan, and Kok Leong Von. 2017. "Techno-Economic Evaluation of Roof Thermal Insulation for a Hypermarket in Equatorial Climate: Malaysia." *Sustainable Cities and Society Journal* 35:209–23.
RIMA International. 2014. Understanding and Using Reflective Insulation, Radiant Barriers and Radiation Control Coatings.
Saber, Hamed H. 2012. "Investigation of Thermal Performance of Reflective Insulations for Different Applications." *Building and Environment* 52:32–44. Retrieved (http://dx.doi.org/10.1016/j.buildenv.2011.12.010).
Tenpierik, Martin J. and Evert Hasselaar. 2013. "Reflective Multi-Foil Insulations for Buildings: A Review." *Energy and Buildings*.