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Thermal Characterization and Performance of Reflective Insulations and Radiant Barriers using Heat Flow Meter

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Abstract

Heat gain into buildings is the major concerns in hot climate because energy for cooling accounts for the highest energy consumption in building. One of the most effective passive cooling methods to reduce radiant heat flow into building is by using reflective insulation and radiant barriers. Reflective insulations and radiant barriers are insulation materials that have low emissivity which ranges from 0.03 to 0.04 and high reflectance values in the solar thermal spectrum especially the infra-red wavelength. Reflective insulation are characterized by an enclosed air spaces adjacent to low-emittance surfaces whereas radiant barrier are related with large ventilated or unventilated air spaces. The measurement of thermal resistance for both of these insulations are measured in R-value and expressed in meter squared Kelvin per watts (m^2.K/W). The characterization and performance of reflective insulations and radiant barriers can be measured according to ASTM C518 using Heat Flow Meter. The objective of this paper is to present the performance characteristics of three different types of reflective insulations namely the big bubble aluminum foil, small bubble foil and woven foil with different air gaps. Based on the Heat Flow Meter measurement of various assemblies of enclosed thickness of air spaces with the reflective insulation, 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; radiant barriers, heat flow, heat gain, emissivity, R-value

1. Introduction

In order to achieve high saving of energy in buildings, the need of an effective insulation assemblies is highly required. Typically, in tropical countries with high solar radiation intensity being absorbed by buildings components which causes high amount of solar heat gain emitted inside the building will increase the energy consumption for cooling purposes [1]. Therefore, for this reason, decreasing the solar heat gain became a big challenge especially in designing green and low energy buildings [2].

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[3]. The insulation materials and assemblies are commonly found in 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 [4]. Therefore, most of the studies found on building insulations were conducted on roofs as compared to other building components like walls, façade and floors components. The large size roof of buildings in hot climate especially the non-residential buildings such as airports, shopping malls, industrial factories and exhibition halls with proper insulation could able to reduce up to 50% of thermal heat gain inside the buildings[4]. 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 facade.

There are mainly two major categories of building insulations namely the mass or bulk insulation and reflective insulation or radiant barriers. 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 [5]. Hence, reflective insulation and radiant barriers are the very effective in reducing radiant heat transfer. The thermal performance of reflective insulation and radiant barriers are highly dependent of the thermal properties of its materials and assemblies as building components [6]. The key parameters that influence the performance of reflective insulation and radiant barriers 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 insulation and radiant barriers. The standard thermal characterization methods to evaluate the performance of reflective insulation and radiant barrier 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[1]. In this study, the heat flow meter characterization method is used for different thermal insulation assemblies. [5] Pei-Chi Chang et al. evaluated a double roof prototype insulation assemblies using radiant barriers. It was found that the radiant barriers system assemblies was very effective in reducing the radiative heat transfer from roof to the ceiling. To obtain the value of the thermal resistance of different radiant barriers used in building insulation, Escudero et al [1] tested different radiant barriers systems using the heat flow meter apparatus together with the guarded hot box method. Two different configurations have been tested and compared with simple analytical model according to ISO6946 standards using CFD analysis. It was concluded that the experimental lab tests were all suitable for the thermal evaluation in order to obtain the proper characterization of radiant barriers.

For a large area of metal roof type building, J. P. Brito Filho and T. V. Oliveria Santos [2] presented a comparative analytical study of the thermal performance. The study was conducted for the building constructed in the tropical climate. Based on heat transfer modelling through the roof of an exhibition hall in Brazil, the survey of their study was conducted using transient time method where the ambient temperature and solar radiation was functioned with time. 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. On aspect of different weather conditions, W. Guo et al [7] studied the effect of energy saving of reflective insulation on exterior building envelopes. 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 and radiant barriers 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 aluminium foil, small bubble aluminium foil and woven foil with variable air gap.

2. Problem identification and research objective

The reflective insulation product is still a fairly new product that was just introduced onto the building market lately as a highly promising new type of thermal insulation material. Due to the claim of its high performance, it has triggered numerous ongoing debate on this issue particularly in comparison with mass insulation like rockwool [8]. Both types of reflective insulation and mass insulation have different functions and application. 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 and due to its low emissivity surfaces, it is very effective in reducing radiant heat transfer as much as 97% [9].

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 Fig 1.

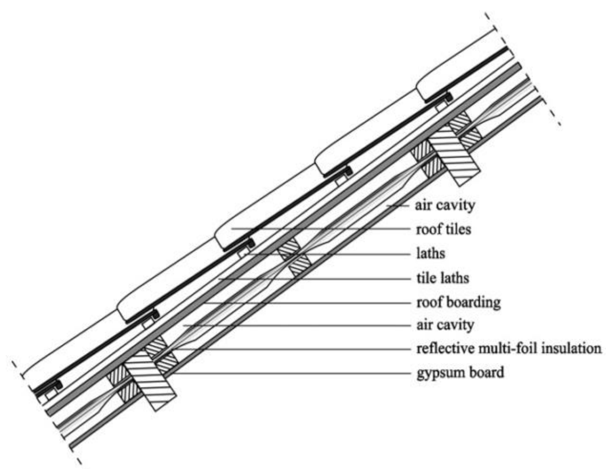

Fig 1 Example of roof construction with reflective foil Insulation [8]

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

(a) (b)

(c)

Fig. 2 (a) Small bubble foil; (b) Big bubble foil (c) Woven 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 [10]. 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 Fig 3.

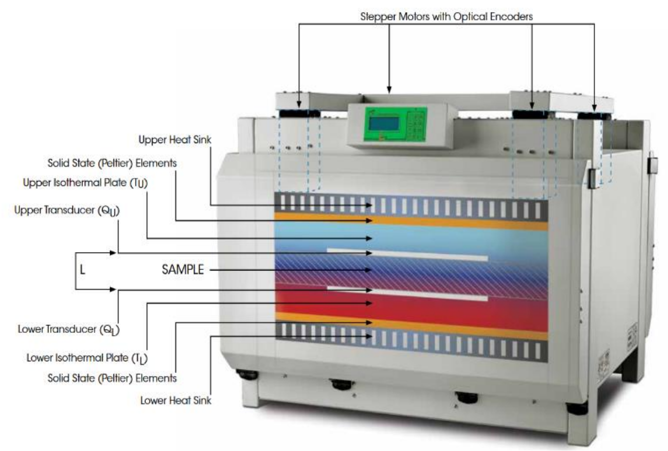

Fig 3 LaserComp Model FOX 600 Heat Flow Meter [11]

The heat flow meter is a steady state technique for the measurement of thermal conductivity and it is also commonly used by researchers and industry professionals to determine the R-value of the insulation materials. In order to measure the thermal conductivity of the assemblies of the reflective insulation, the heat flow meter, a sample is positioned 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 and this 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:

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

$$R = \frac{1}{\lambda} L \quad \text{m}^2\text{K/W} \qquad (2)$$

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

Fig 4 Timber frames are used to create top and bottom air gaps for bubble foil for heat flow meter 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 heat flow through the sample assembly was downwards flow direction as shown in Fig 5. The sample size was 600mm x 600mm with different configurations of air gaps that ranges from 25mm, 50mm, 75mm, 100mm, 125mm and 150mm.

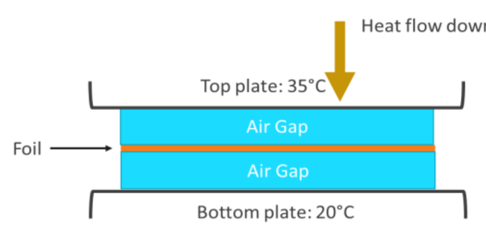

Fig 5 Diagram of the heat flow meter top and bottom plate temperature settings, air gaps and heat flow downwards direction

All the heat flow meter measurement settings for small bubble foil, big bubble foil and woven 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 discussions

Based on the heat flow meter measurement and R-value calculations for big bubble foil, the optimum R-value achieved was 2.38 m^2K/W with top air gap of 50mm and bottom air gap of 75mm as shown in Fig 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 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.

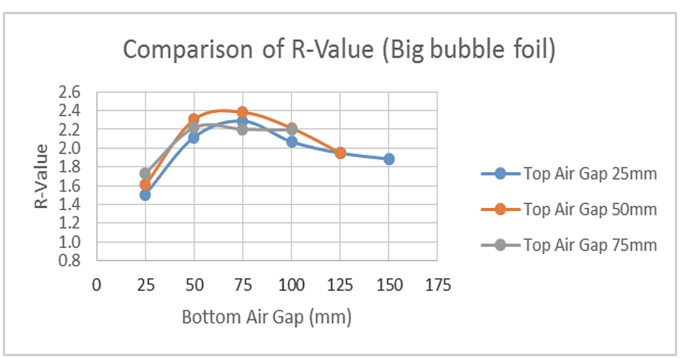

Fig 6 Thermal resistance or R-value (m^2K/W) for Big Bubble Foil with different air gaps configurations

Fig 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 m^2K/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.

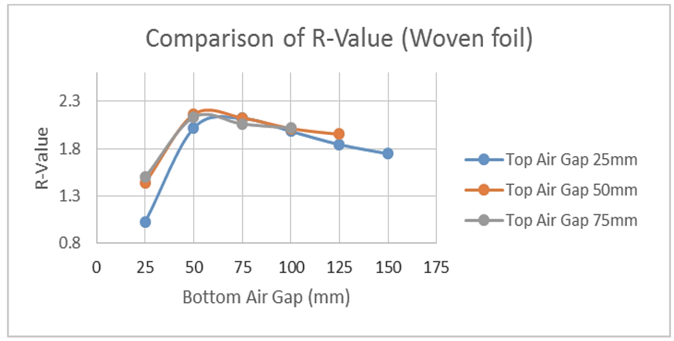

Fig 7 Thermal resistance or R-value (m^2K/W) for Woven foil with different air gaps configurations

Fig 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 m^2K/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.

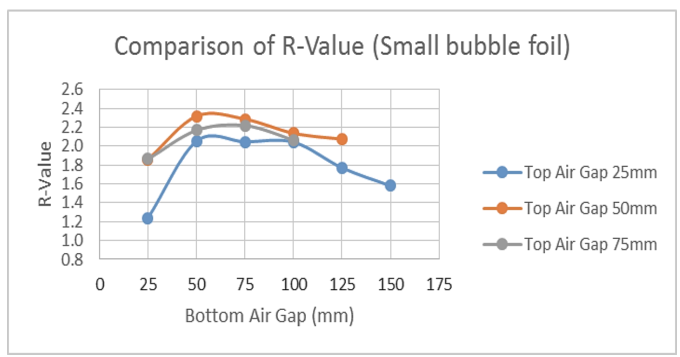

Fig 8 Thermal resistance or R-value (m^2K/W) for Small bubble foil with different air gaps configurations

Table 2 shows the summary of the performance of all the 3 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

5. Conclusions

Reflective insulation and radiant barrier are good insulation to reduce the solar radiant heat gain with heat flow downwards from the roof. Based on this study, the R-value for the three types of reflective insulation namely big bubble foil, small bubble foil and woven foil ranges from 2.16 m^2K/W to 2.38 m^2K/W. The highest R-value was the big bubble foil with R-value of 2.38 m^2K/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 encountered by other researchers on the studies on reflective insulation 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.

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Commonwealth Energy and Sustainable Development Network (CESD-Net)

CESD-Net is a major global initiative in energy and sustainable development. The objective of network is to promote energy and sustainable development in commonwealth countries.
Focussing on Multidisciplinary Research, Promoting Future Low Carbon Innovations, Transferring Knowledge and Stimulating Networking among Stakeholders to Ensure the UK Achieves World Leading Status in Energy and Sustainable Development. https://www.weentech.co.uk/cesd-net/

The 1st International Conference on Energy, Environment and Economics (ICEEE 2016) was held at Heriot-Watt University, Edinburgh, EH14 4AS, UK, 16-18 August 2016. ICEEE2016 focused on energy, environment and economics of energy systems and their applications. More than fifty eight delegates from 31 countries with diverse expertise ranging from energy economics, solar thermal, water engineering, automotive, energy, economics and policy, sustainable development, bio fuels, Nano technologies, climate change, life cycle analysis etc. made conference true to its name and completely international. During conference total 51 oral presentations and six posters were shared between delegates. The presentations showed the depth and breadth of research across different research areas ranging from diverse background. ICEEE2016 aimed:

- To identify and share experiences, challenges and technical expertise on how to tackle growing energy use and greenhouse gas emissions and how to promote sustainability and economical, cost effective energy efficiency measures.

In total 11 technical sessions and two invited talks both from academia and industry provided insight into the recent development on the proposed theme of the conference. Preparation, organisation and delivery of the conference started from July 2015 and further co-ordinated by vibrant team of Conference Centre, Heriot Watt University. Conference organisers would like to acknowledge support from the sponsors particularly World Scientific Publication ltd and its team members for the delivery of the conference. Organisers are also thankful to all reviewers who contributed during peer review process and their contributions are well appreciated. At the end and during vote of thanks following awards have been announced and we would like to congratulate all well deserving delegates.

- Best Paper –Academia: Amela Ajanovic, EEG, TU Vienna, Austria
- Best Paper – Student : Christian Jenne,University of Duisburg-Essen, Germany
- Best Poster – Student: Yoann Guinard, University of New South Wales, Sydney, Australia
- Best Poster – Academia: E. Salleh, Universiti Kebangsaan Malaysia, Malaysia
- Active Participation Award - Yoann Guinard, University of New South Wales, Sydney, Australia

At the end we would like to extend our gratitude to all of you for your participation and hopefully welcome you again during ICEEE2017.

Editors:
Dr. Singh is Senior Scientist at Indian Agricultural Research Institute, New Delhi, India. Her area of expertise are bio energy and bio fuels, environmental engineering, carbon accounting and renewable energy integration for rural development.
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