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Effectiveness of Aerogel Roofing System on Temperature Reduction in Malaysian Residential Buildings

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Abstract: Malaysia is located in the tropical region near to the equator, exposed to long hours of sunshine and experiences high temperature and relative humidity throughout the year. In tropical countries, 75% of the heat generation in a house come from the roof. Based on previous research, installing insulation on roof has successfully given positive impacts on indoor temperature reduction. It was discovered that aerogel is the current best solid insulation material where it has the lowest thermal conductivity of 0.02 W/m.K. However, current usage of aerogel was only restricted in aeronautics, military, vessels and piping insulation. The efficiency of aerogel as roof insulation material was simulated using Ecotect Analysis 2011 and to demonstrate the real condition, the indoor and outdoor temperature of three small-scale houses was measured. The results obtained from all stages of this research shows that aerogel induced the highest outdoor-indoor temperature differences up to 8.1°C compared to aluminium foil and stone wool. From the energy saving cost analysis, it was shown that aerogel reduced the energy cost in comparison with non-insulated roof the highest by 89%. These results support the effectiveness of aerogel as roof insulation in residential building. It is recommended to demonstrate the installation of aerogel in real house and further analysis on cost benefit analysis to be done in future research.

Key words: Aerogel, thermal insulation, hot climate, residential building, future research, Malaysia

INTRODUCTION

The government of Malaysia has launched the National Climate Change Policy on 30th August 2010 to reduce Greenhouse Gases (GHGs) up to 40% by 2020 as compared to 2005 based on the carbon intensity (Adham *et al*., 2013). According to the international energy agency estimation, the increment of global energy consumption for 10 years ahead will be up to 53%. Rapid development of industrial and human activities leads to this significant result (Ong *et al*., 2011). The term "global warming" refers to the rise in average surface temperature of the Earth which occurs as a consequence of the presence of atmospheric GHGs in the atmosphere which traps heat from escaping to space (Akorede *et al*., 2012). Gradual increase in the overall temperature of Earth due to the greenhouse effect will cause tropical countries to experience high levels of heat radiation from the sun which leads to discomfort to humans and their surroundings. Malaysia is geographically located in the tropical region near to the equator which makes it exposed to long hours of sunshine and experience high temperatures and relative humidity throughout the year

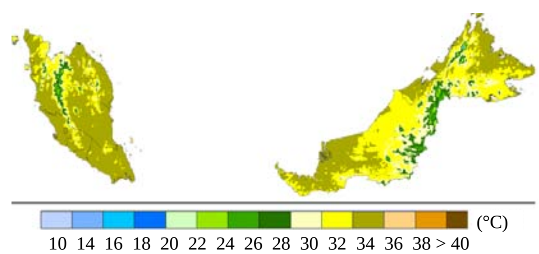

Fig. 1: Maximum temperatures experienced throughout the whole of Malaysia

(Yacouby *et al*., 2011). Previously, the daily air temperature in Malaysia varies from 24°C up to a maximum of 38°C as shown in Fig. 1.

High temperatures and relative humidity contribute to high energy consumption from buildings. About 25% of the energy used is electrical energy that is used to provide thermal comfort to the occupants. Aswathanarayana (2010) reported that buildings had consumed 2914 Mtoe of energy thus, it is constituted as the largest user of electricity. Buildings are generally grouped into residential and non-residential buildings.

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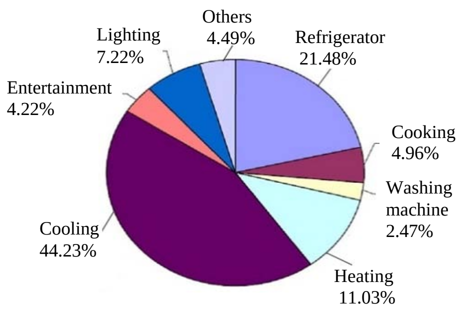

Fig. 2: Average electricity consumption from various sources in houses (%) (Lalchand, 2012)

The non-residential groups are further categorized as commercial and industrial buildings. The residential and industrial sectors account for two-thirds of the energy use, respectively. As shown in Fig. 2 about 44.23% of electricity consumed in a house is used for cooling. In average more than 56% of the houses have installed air conditioning (Lalchand, 2012). Air conditioning is a major consumer of energy and accounted for 50% of the electricity cost in a house. Meanwhile, Tenaga Nasional Berhad (TNB) has announced a new electricity tariff for domestic consumers starting effectively from 1st January, 2014 (TN, 2014).

In tropical countries, 70% of the heat generation in a house comes from the roof (Vijaykumar *et al*., 2007). Numerous studies have been conducted to study the impact of insulation materials used in roofing systems on indoor temperature reduction. As stated by the Malaysian Insulation Manufacturers Group (MIMG) it was proved that insulation can reduce indoor temperatures by 3-5°C based on a study conducted under local climate conditions (Ganesan, 2011).

The placement of thermal insulation under the roof in hot weather place like North Cyprus can save the energy up to 28% by reducing the heat gain and providing thermal comfort (Ozdeniz and Hancer, 2005). Aerogel was discovered as potential promising insulation material as it has low thermal conductivity. Many attempts have been conducted to reinforce the properties of Aerogel with other compatible materials to overcome the brittleness issue (Puad *et al*., 2015). This study, aims to determine the effectiveness of aerogel as an insulation material in the roofing system of residential buildings by comparing it with two insulation materials that are commonly used in Malaysia and available in the market today which are aluminium foil and stone wool.

MATERIALS AND METHODS

Ecotect simulation: A 3D residential building model was developed using Ecotect (Fig. 3 and 4) shows the roof system cross-section, consists of a the 10 mm thick plasterboard ceiling, concrete tiles and a 50 mm thick insulation with an air gap. Concrete was employed for the wall material and the climate of Kuala Lumpur, Malaysia is adopted for simulation. Three variants of room insulation material were chosen; aerogel, aluminium foil and stone wool. Indoor and outdoor temperatures from 9.00 a.m. to 5.00 p.m. are recorded for 7 days.

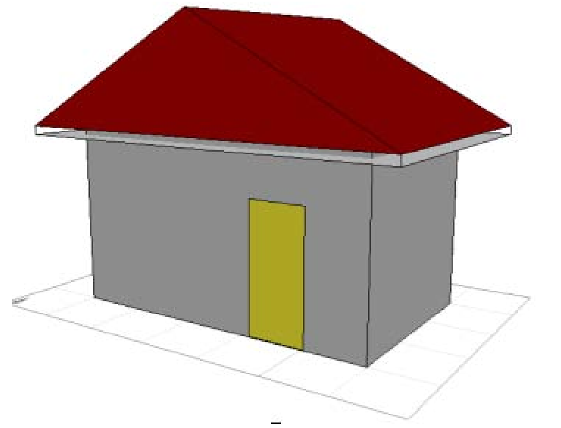

Fig. 3: 3D residential building model developed in Ecotect

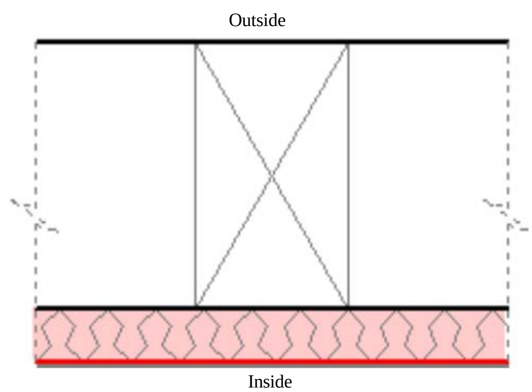

Fig. 4: Cross-section of the roof developed in Ecotect

Field measurement: Three small-scale residential building models were constructed with concrete wall and red concrete roof tiles to validate the findings from Ecotect simulation (Fig. 5). The dimensions are 600 cm in length by 600 cm width by 600 cm in height with 45° roof slope. The models were located behind the concrete laboratory of the Civil and Environmental Engineering Department, Block 13 in Universiti Teknologi PETRONAS, Perak, Malaysia. No windows were built on the wall of experimental houses to create air-tight condition. The wider area of roof was positioned to face the North and South. As the sun rises in the East and sets in the West the East-west orientation of the long axis of the roof can

Fig. 5: Small-scaled residential building models

Fig. 6: Hygrometer

minimize the heat gain due to sun radiation. Indoor and outdoor temperatures were measured with the hygrometer as shown in Fig. 6. Temperature readings for each experimental house were taken for every 1 h of interval.

RESULTS AND DISCUSSION

From the graph analysis, observation the daily outdoor temperatures peak recorded was in between 9.00 a.m. to 5.00 p.m. because of the position of the sun which leads to maximum solar radiation.

Indoor temperatures from the adoption of aerogel, aluminium and stone wool as roof insulations are compared using the Ecotect simulation. Based on the temperature profile for the aluminium-insulated model graph (Fig. 7) the highest outdoor-indoor temperature difference recorded is 7.4°C at 1.00 p.m. in day 2.

Meanwhile for the stone wool-insulated model (Fig. 8) day 2 data record has shown that the highest temperature difference with 7.5 was observed at 3.00 p.m. In contra with the outdoor-indoor temperature difference obtained by the aluminium-insulated model on the same day and time which was 7.2°C. A difference of 0.3°C less than the stone wool-insulated model. Thus, stone wool performed more effectively than aluminium in retarding heat into the model.

The aerogel-insulated model outdoor-indoor temperature difference has generated the highest outdoor indoor temperature difference with 8.2°C at 1.00 p.m. in day 2 as illustrated in Fig. 9. Aerogel-Insulated Model has obtained the highest temperature difference as compared to the aluminium and stone-wool insulated model with 0.8-1.1°C difference, respectively. Therefore, aerogel performed more effectively than both aluminium and stone wool.

Figure 10 and Table 1 present comparisons of the outdoor-indoor temperature differences of all models. The thermal performances of all models from 9.00-10.00 a.m. do not differ too much from one another. However, from 11.00 a.m. to 3.00 p.m. the aerogel-insulated model starts to perform better than the aluminium and stone wool insulated models. The highest outdoor-indoor temperature difference of 8.6°C was recorded at 1.00 p.m. which is obtained by the aerogel-insulated model. Therefore, ecotect simulation findings suggest that aerogel can perform better as a roof insulation material than aluminium and stone wool. Aerogel induced the highest outdoor-indoor temperature difference followed by stone wool and aluminium (Table 1).

Based on the entire graphs above it was shown that aerogel performance is better than aluminium and stone wool since the outdoor-indoor temperature differences among these insulation materials varies up to ±1.1°C. From all the graphs it can be concluded that aerogel can perform effectively as roofing insulation than aluminium and stone wool.

Figure 10 outdoor-indoor temperature differences of all insulated models. There are certain limitations when conducting the simulation using software. Thermal analysis generated by the software is based on mathematical equation. In real condition analysis the indoor temperature is related to many different factors. Figure 11 shows the outdoor-indoor temperature profiles of experimental houses.

Field measurements were conducted to validate the Ecotect simulation results. The indoor temperatures obtained for the aluminium and stone wool-insulated houses were higher than the outdoor temperatures due to high relative humidity which varies from 60-70% and the radiation of heat from the interior walls. However, the aerogel-insulated model performed differently as its indoor temperatures were lower than the outdoor temperatures with 50% of relative humidity. Therefore this result is enough to prove the effectiveness of aerogel as roof insulator comparison in with aluminium and stone wool and supports the results obtained from the Ecotect simulation.

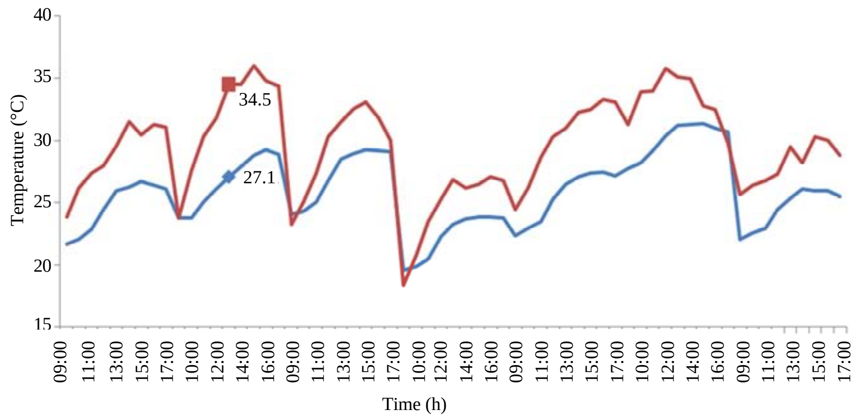

Fig. 7: Temperature profile for the Aluminium-Insulated Model

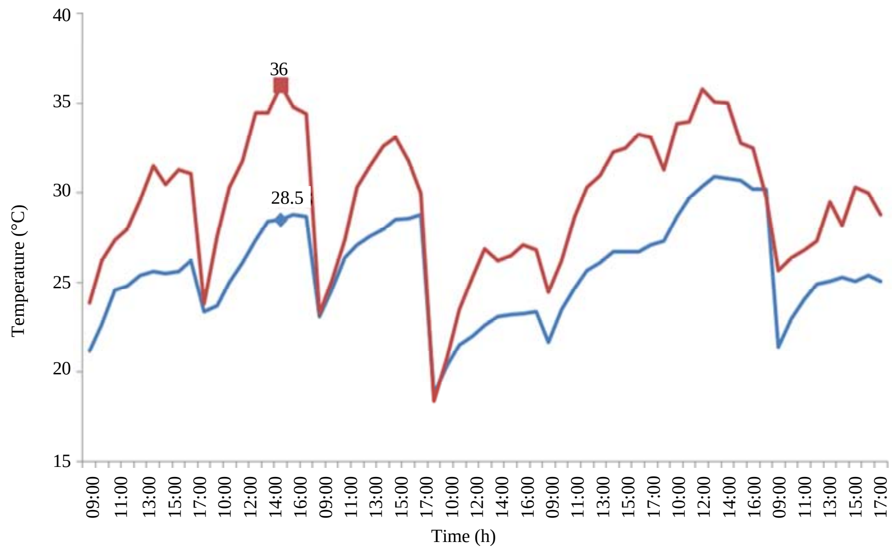

Fig. 8: Outdoor-indoor temperature difference for Stone Wool-Insulated Model

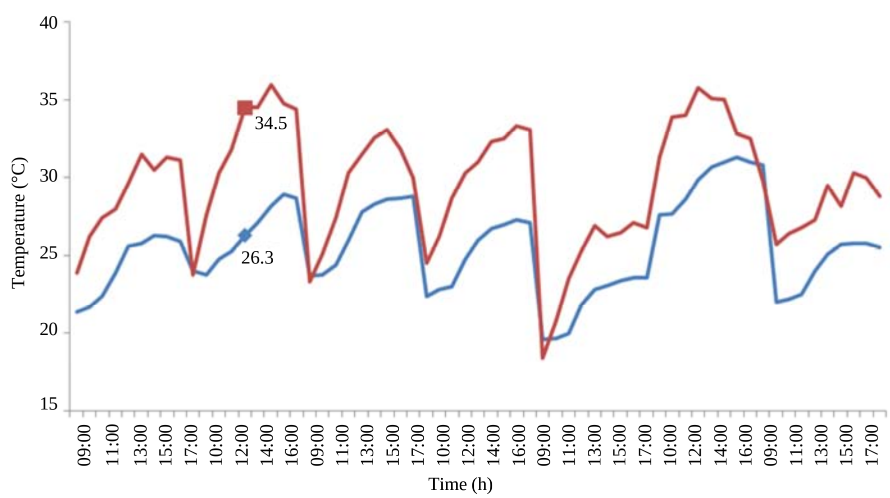

Fig. 9: Outdoor-indoor temperature profile for Aerogel-Insulated Model

Table 1: Outdoor-Indoor temperature differences between insulation materials

	Outdoor-indoor temperature differences		
Time (h)	Aluminium	Stone wool	Aerogel
9:00 a.m.	0.50	1.00	0.5
10:00 a.m.	3.70	4.20	4.1
11:00 a.m.	5.90	6.00	6.6
12:00 p.m.	7.40	6.70	8.3
1:00 p.m.	7.70	7.20	8.6
2:00 p.m.	5.40	5.30	6.1
3:00 p.m.	4.00	3.80	4.3
4:00 p.m.	4.40	4.40	4.5
5.00 PM	3.00	3.60	2.9
Average	4.67	4.69	5.1

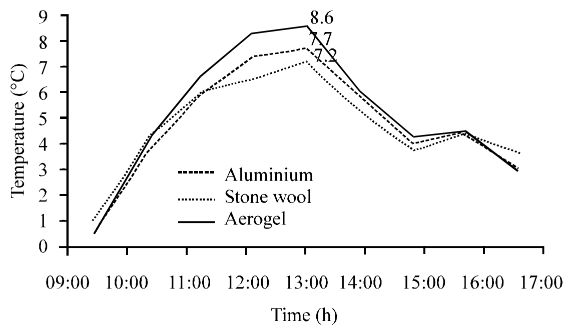

Fig. 10: Outdoor-indoor temperature differences of all insulated models

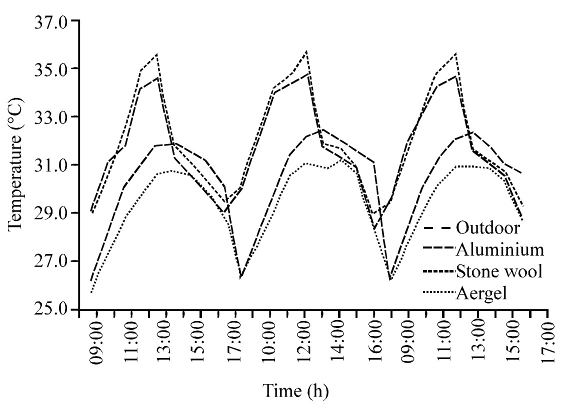

Fig. 11: Outdoor-indoor temperature profiles of the experimental houses

CONCLUSION

Findings from the Ecotect simulation suggest that aerogel performs the best as roof insulation, followed by aluminium and then stone wool. The findings are validated by field measurements. In order to further understand the effect of aerogel on the thermal performance of residential buildings more research has to be conducted. Potential areas for further exploration include:

- Incorporation of aerogel with other materials such as plastic to yield better performances
- Adoption of the most common roof materials and colours in addition to testing the effect of aerogel with other insulation materials
- Evaluation of the effect of aerogel roofing system on indoor temperatures at night

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