Techno-economic evaluation of roof thermal insulation for a hypermarket in equatorial climate: Malaysia

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***Abstract* — Energy conservation in building is important because energy consumption in buildings account for about 40% of total world energy. Roof thermal insulation is one of the effective measures to reduce heat gain into building and thus lowering building energy consumption. The economic benefits for investment in roof thermal insulation is often linked to the monetary savings from decrease in electricity consumption. Therefore, the focus of this study is to carry out techno-economic analysis to evaluate the monetary savings of commonly used roof thermal insulation for a typical hypermarket in Malaysia. The aim is to identify the most cost effective type of roof thermal insulation material which offers the greatest economic benefits. There are 4 methodological stages involved to achieve the objectives of this study i.e. collating market information via expert interview, laboratory measurement, building modelling & thermal simulation and economic evaluation. The economic evaluation methods used include life-cycle savings, discounted payback period and internal rate of return. Eight commonly used thermal insulation systems for a typical hypermarket in Malaysia have been identified and evaluated. It is found that small bubble aluminium foil ranked first with the highest life-cycle savings, internal rate of return and shortest payback period.**

Keywords* — *Roof insulation; Techno-economic evaluation; Thermal resistance (R-value)

I. Introduction

It is very important to implement energy conservation in building because energy consumption in buildings account for about 40% of total world energy. Approximately 60% of the world's electricity is consumed by residential and commercial buildings [1]. Malaysia being one of the fastest growing countries in Southeast Asia has recorded a significant increase in energy consumption in recent years. The electricity consumption per capita in Malaysia has increased from 1,101 kWh in 1990 to 4,110 kWh in 2013 [2]. The increase of almost fourfold in less than 25 years is very alarming. Cooling equipment and appliance account for about 50% of electricity demand in buildings in 2013 and this is expected to increase to 57% by 2040 [3].

Weather conditions which include outdoor air temperature, solar radiation, etc. is one of the major determinants that influence building energy consumption [4][5][6]. Malaysia is located in the Southeast Asia near the equator, a region characterized as hot and humid all year round. Most of the heat gain into the building through the building envelope is in the form of radiation compared to conduction and convection. Vijayakumar et al. [7] and Michels et al. [8] both agreed that the greatest heat transfer into a building occurs through the roof especially in tropical countries. Roof is the most important structural element of a building for reducing energy consumption [9][10][11]. It is imperative to include passive cooling strategy during the design of building roof. One of the passive cooling measures for roof is thermal insulation. Dylewski & Adamczyk [12] and Daouas [13] both agreed that thermal insulation is one of the most effective way to conserve energy in building. Suehrcke et al. [14] stated that one of the ways to reduce downward heat transmission from the roof is through the use of reflective foil. On average, radiant barrier which uses reflective foil installed on attic space can reduce heat flux to conditioned space by 26% to 50% during summer season [15]. This is because reflective insulation technology that uses very thin layer of low-emittance aluminium foil is very effective in blocking the transfer of heat through radiation which is the major heat source in Malaysia.

Throughout the past 30 years, there have been a limited number of research publications examining the economic aspect of thermal insulation for roof. A number of researchers [11][16][17][18][19][20][21] investigated the optimum insulation thickness for roof in terms of economic benefits and payback period. These studies, each adopting different insulating materials in respective research climates predicted the optimum insulation thickness for roof to be in the region of 0.02 to 0.187m. The payback periods obtained from some of these studies [10][17][19][21][22][23][24] were less than 10 years with the longest 13 years as predicted by Ramamurthy et al. [20]. Most of the studies were carried out in countries with temperate climate mainly using conventional bulk insulation materials in residential building. Economic analysis to examine the roof insulation for other types of building such as hypermarket in equatorial climate like Malaysia is still lacking.

Therefore in this present paper, a techno-economic analysis has been carried out to evaluate the economic benefits of using roof insulation in a hypermarket with insulation system which is common in Malaysia. The aim is to identify the most cost effective type of insulation materials which offer the greatest economic benefits.

II. Research Methodology

This paper focuses on techno-economic evaluation of roof insulation system for a single-storey hypermarket model. The hypermarket was modelled with reference to an actual roof surface area of a hypermarket building found in Klang Valley, Malaysia. The model has a lightweight 0.47mm-thick metal deck roofing, steel structure, 150mm-thick common brick wall and fixed rectangular clear glass window which is typical for a hypermarket in Malaysia. Hypermarket in Malaysia is seen to flourish for the past two decades. The long operating hours of a hypermarket indicates a very high usage of air-conditioning. Hence, the studies on economic benefits of roof insulation system to hypermarket is worthwhile.

Briefly there are four methodological stages involved in this study:

A. *Stage 1 – Collating market information*

The study began with collating of market knowledge by conducting expert interview with manufacturer, distributor, roofer and contractor who are expert in the building insulation in Malaysia. The key issues that were discussed and addressed during the interview include common insulation materials used, its system and the corresponding costing for installation of a typical hypermarket roof in Malaysia. The information gathered on commonly used insulation materials, systems and costing are summarized in Table 1. The insulation system can be explained as insulation assembly that includes the insulation material and air cavity. For this study, 8 common roof insulation systems were investigated (i.e. case 1 to 8 as shown in Table 1. Each case of insulation system is identified by the insulation material type which is commonly used for a hypermarket in Malaysia.

B. *Stage 2 – Laboratory measurement*

With market information from section A, sample specimens of the commonly used insulation materials were tested using heat flow meter apparatus (Fig. 1) which is in accordance to the American Society for Testing and Materials (ASTM) standard, ASTM C518 [25] and Malaysia Standard, MS2095: 2014 [26]. The purpose is to find the thermal resistance or R-value of the thermal insulation system.

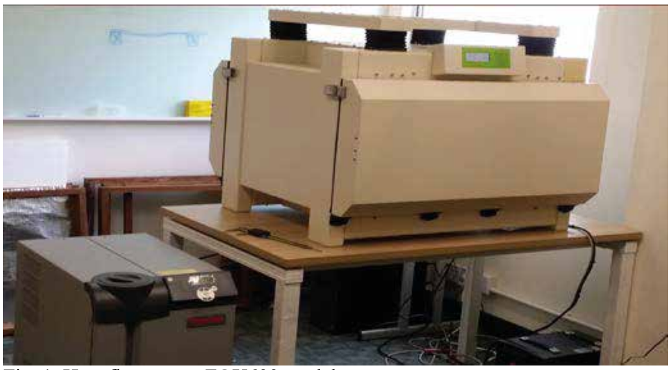

Fig. 1. Heat flow meter FOX600 model

It should be noted that the R-value obtained from the heat flow meter represent the test insulation system configurations. Accordingly system thermal transmittance or U-value is the reciprocal of R-value. This U-value was inserted into the simulation program under stage 3 in section C.

C. *Stage 3 – Building Modelling and thermal simulation*

A 3D model hypermarket with area 15,607.46m^2 (represents actual size of a hypermarket building found in Klang) was designed and constructed in Integrated Environment Solutions - Virtual Environment (IES <VE>) software. The model building of the hypermarket is shown in Fig. 2. In this study, our purpose of the thermal simulation is to generate energy consumption with the commonly used insulation system for a hypermarket. To run the thermal simulation for this purpose, the main input data required by IES <VE> is U-value of insulation system obtained from section B. In addition, daily profile for air-conditioning, lighting and equipment (i.e. freezer) operating hours and occupancy are set for the model hypermarket. The weather file used in the simulation was based on the weather station nearest to the hypermarket (within 10 km radius) which is Subang Jaya weather station. The thermal simulation analysis was run for each case as shown in Table 1 and a base case (i.e. case without insulation).

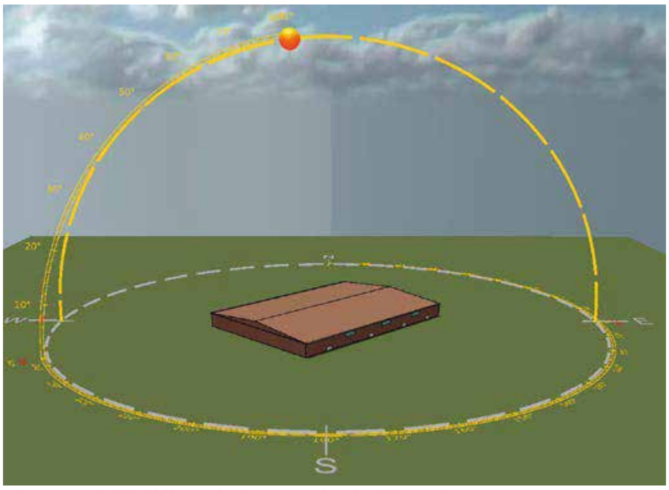

Fig. 2. Model building of a hypermarket in this study

Table 1. Commonly used insulation materials, systems, costing, R-value, corresponding U-value and annual cooling energy consumption for a hypermarket roof in Klang Valley, Malaysia

Case	Insulation materials	Sample specimen trade name	Technical parameter of specimen	Insulation system	Cost of insulation system	R-value	U-value (1/R-value)	Annual cooling energy consumption
					MYR/m^2	m^2.K/W	W/m^2.K	kWh
0	Base case (non-insulated roof)	Nil	Nil	== Air gap of 80mm	Nil	0.195	5.128	256,805.70
1	Rock wool + metallized foil	Rock wool: Thermal Rock B40 Foil: Coolmax CMF2	Rock wool: 50mm nominal thickness & density 40kg/m3 Foil: 0.16mm both sides metallized foil laminated to woven material, non-fire retardant	== 13.24mm rock wool (compressed) == Foil 0.16mm == 50mm lower air cavity	22.69	1.370	0.730	183,074.30
2	Rock wool + aluminium foil	Rock wool: Thermal Rock B40 Foil: Coolmax Barrier FR Net	Rock wool: 50mm nominal thickness & density 40kg/m3 Foil: 0.16mm both sides aluminium foil laminated to fiber material, fire retardant	== 12.46mm rock wool (compressed) == Foil 0.16mm == 50mm lower air cavity	28.44	1.841	0.543	163,891.80
3	Glass wool + metallized foil	Glass wool: Ecowool Classic Foil: Coolmax CMF2	Glass wool: 50mm nominal thickness & density 10kg/m3 Foil: 0.16mm both sides metallized foil laminated to woven material, non-fire retardant	== 4.46mm glass wool (compressed) == Foil 0.16mm == 50mm lower air cavity	17.01	0.946	1.057	194,358.30
4	Glass wool + aluminium foil	Glass wool: Ecowool Classic Foil: Coolmax Barrier FR Net	Glass wool: 50mm nominal thickness density 10kg/m3 Foil: 0.16mm both sides aluminium foil laminated to fiber material, fire retardant	== 4.15mm glass wool (compressed) == Foil 0.16mm == 50mm lower air cavity	22.76	1.581	0.633	170,815.60
5	Small bubble aluminium foil	Coolmax Select 40+ FR Net	4mm both sides aluminium foil, fire retardant, anti-corrosion	== 30mm upper air cavity == Foil 4mm == 50mm lower air cavity	15.54	2.103	0.476	158,270.60
6	Big bubble aluminum foil	Coolmax Select 80 FR Net	8mm both sides aluminium foil, fire retardant, anti-corrosion	== 30mm upper air cavity == Foil 8mm == 50mm lower air cavity	19.62	2.124	0.471	157,817.50
7	Bubble + foam foil (9mm)	Coolmax Triplex FR Net	9mm both sides aluminium foil, fire retardant, anti-corrosion	== 30mm upper air cavity == Foil 9mm == 50mm lower air cavity	28.63	2.302	0.434	154,378.00
8	Double big bubble foil (16mm)	Coolmax Polyshield Extra	16mm both sides aluminium foil, fire retardant, anti-corrosion	== 30mm upper air cavity == Foil 16mm == 50mm lower air cavity	29.59	2.529	0.395	150,520.80

D. Stage 4 – Economic evaluation

As shown in Fig. 3, each of the 8 cases of roof insulation system will be compared to the base case (case 0) scenario and only the investment cost i.e. money spent to add insulation system is considered in this economic evaluation. Annual savings is the annual electricity savings resulted from improved thermal resistance after adding roof insulation system in relation to base case or non-insulated roof. The investment costs include the material, labour and transportation cost of installing roof insulation. The economic evaluation methods used to evaluate the 8 cases in this study are life-cycle savings (LCS), discounted payback period (DPP) and internal rate of return (IRR).

i) LCS

This method includes the sum of current investment costs and annual savings derived from installing roof insulation system over its lifetime in relation to the non-insulated roof. The formula for LCS calculation is:

$$LCS = \sum_{t=0}^{n} \frac{S_t - C_t}{(1+d)^t} \quad (1)$$

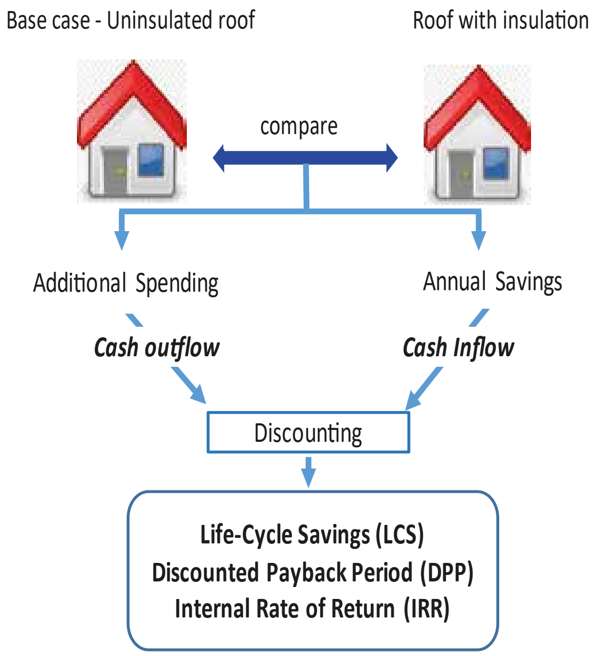

Fig. 3. Economic evaluation

where t is the time period in year; S_t and C_t is the annual savings (cash inflows) and investment cost (cash outflows) respectively for year t for the insulated roof compared with the base case; n is the roof insulation system lifetime usually in number of years; and d is the discount rate or cost of capital. As various roof insulation systems are compared in the present study, the best of them would be the one with the highest LCS value from the economic perspective.

ii) DPP

This method determines the number of years that are required to recover the initial cash outflow of an investment. In this present study, the initial investment cost can be recouped through the electricity bills savings (cash inflow) that are expected after installing roof insulation system. The formula for DPP calculation is:

$$DPP = (T-1) + \frac{C_0 - Cumulative\ PV\ of\ cash\ flow_{(T-1)}}{PV\ of\ cash\ flow_T} \quad (2)$$

where T is the year in which the cumulative present value (PV) of cash flows from investment exceed the initial investment cost; $(T - 1)$ is the year prior to T; PV of cash flow$_T$ is the present value of net cash flow in year T; Cumulative PV of cash flow $(T - 1)$ is the cumulative present value of cash flow from investment at the end of year $(T - 1)$; and C_0 represents the initial cost of investment.

iii) IRR

IRR is an evaluation method to determine the rate of return earned on every money invested in each period of time in the entire evaluation time horizon. IRR can be calculated by solving the discount rate, d when setting the present value of all cash flows of an investment equal to zero. Therefore for our calculation in this present paper, simply set Equation (1) to 0 as shown below:

$$\sum_{t=0}^{n} \frac{S_t - C_t}{(1+d)^t} = 0 \quad (3)$$

The value d solved in Equation (3) is the IRR. When evaluating each examine option using IRR, the general rule is to accept investments with IRR greater than the minimum required rate of return which in most cases is the cost of capital. In essence, investment that yield the highest IRR is the most attractive option.

The parameters used for the calculations of LCS, DPP and IRR for the examined cases in this paper is shown in Table 2. The electricity tariff rate used is as per the current price (i.e. MYR0.365/kWh) charged by the main electricity provider in Malaysia, Tenaga Nasional Berhad for a commercial building [27]. The electricity cost is subject to annual inflation rate of 1.96%. This is based on the average inflation rate for electricity for the past 10 years (2008 – 2017) [28]. Cost of capital or the discount rate employed in the present study is based on the average lending rate in Malaysia. 4.88% is the mean value of average lending rate from 2008 to 2017 [29]. As the actual life span of the insulation materials are indeterminable, 20-year period is adopted as the probable lifetime in this study. 20 years are longer than the shelf life and warranty period of the foil used in this research.

Table 2. Economic parameters for calculations of LCS, DPP and IRR

Input parameters	**Unit of measurement**	**Value**
Electricity tariff rate in Malaysia	MYR/kWh	0.365
Annual increase in electricity cost	%	1.96
Cost of capital, d (per annum)	%	4.88
Investment cost, C_0 for a hypermarket area of 15,607.46m^2	MYR	Refer Table 1 for all the examined cases multiply by area of 15,607.46m^2
Lifetime period	Year	20

III. RESULTS AND DISCUSSION

The results of the evaluation using LCS, DPP and IRR for all the 8 examined cases for a hypermarket in this study are presented in Table 3. The evaluations were calculated based on the economic parameters in Table 2 over a time period of 20 years.

Table 3. Results of economic evaluation using LCS, DPP and IRR

Case	Insulation materials	LCS	DPP	IRR
		MYR	Year	%
1	Rock wool + metallized foil	51,368.85	16.75	6.41
2	Rock wool + aluminium foil	67,124.35	16.64	6.48
3	Glass wool + metallized foil	77,960.37	14.37	7.89
4	Glass wool + aluminium foil	117,695.76	13.87	8.25
5	Small bubble aluminium foil	299,375.60	7.60	15.92
6	Big bubble aluminum foil	238,189.09	9.85	12.22
7	Bubble + foam foil (9mm)	116,482.18	14.84	7.57
8	Double big bubble foil (16mm)	122,712.54	14.77	7.62

By ranking the 8 examined cases according to LCS as presented in Fig 4, reveals that small bubble aluminium foil with the highest LCS is the most attractive insulation material economically. This means with every dollar invested, using small bubble aluminium foil to insulate the roof of hypermarket will yield the highest savings. Big bubble aluminium foil becomes the second preferred option. On the

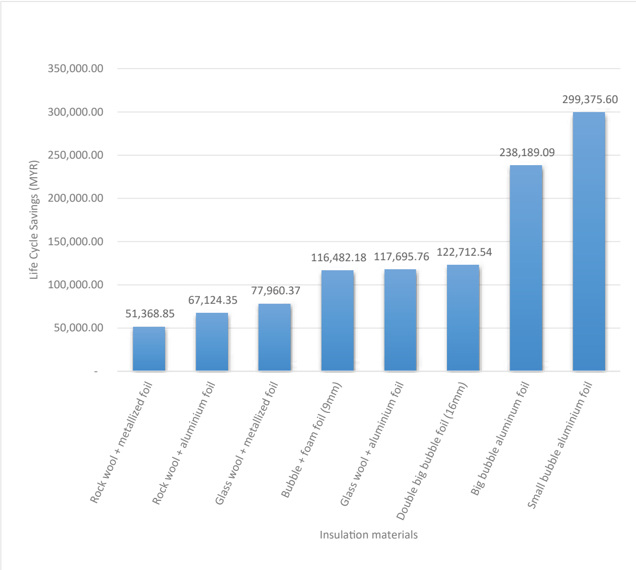

Fig. 4. Ranking of roof insulation systems according to LCS

contrary, insulating roof with rock wool + metalized foil is the least favoured choice economically given the lowest LCS. This can be attributable to the higher initial cost of investment and the lower corresponding energy savings derived compared to other alternatives.

Examining the 8 insulation solutions using DPP again shows a similar findings. From Fig. 5 it is obvious that insulating the hypermarket with small bubble aluminium foil enables the investment cost incurred to be recovered in the shortest period i.e. 7.6 years. This indicates after 7.6 years of installation, this insulation system will generate profit in terms of energy savings in monetary form. While big bubble aluminium foil takes approximately 10 years to breakeven, the remaining 6 insulation systems take more than 10 years with the longest about 17 years when using rock wool and metallized foil. Fig. 5 also shows how fast an investment become profitable.

By analysing the third evaluation method i.e. IRR, from Fig. 6 all the 8 examined cases achieve IRR greater than the minimum required rate of return, 4.88% which is the cost of capital in this paper. Hence, these investments can be pursued. However if only 1 investment can be executed, the one that presents the highest IRR will be the best choice. It is apparent in this study, small bubble aluminium foil produces the highest return i.e. 15.92%. It is about 2.5 times more profitable than rock wool + aluminium foil. The second best choice according to IRR is big bubble aluminium foil. IRR can also be used as a benchmark when sourcing capital for an investment. It represents the highest interest that the investor is willing to pay for financing the investment.

While each of these 3 evaluation methods provides a different perspective on the attractiveness or feasibility of an investment option, it is important to analyse the outcome concurrently to give a more complete view for decision making. Interestingly, the results of LCS, DPP and IRR agreed quantitatively that the most attractive roof insulation system is small bubble aluminium foil given the highest LCS and IRR with the shortest payback period.

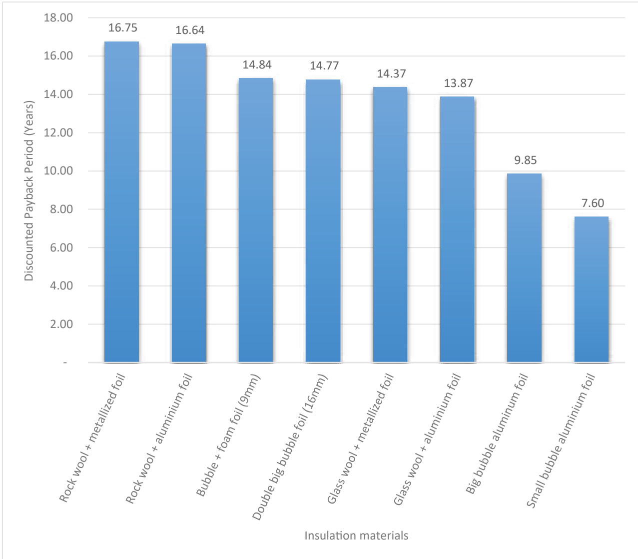

Fig. 5. Ranking of roof insulation systems according to DPP

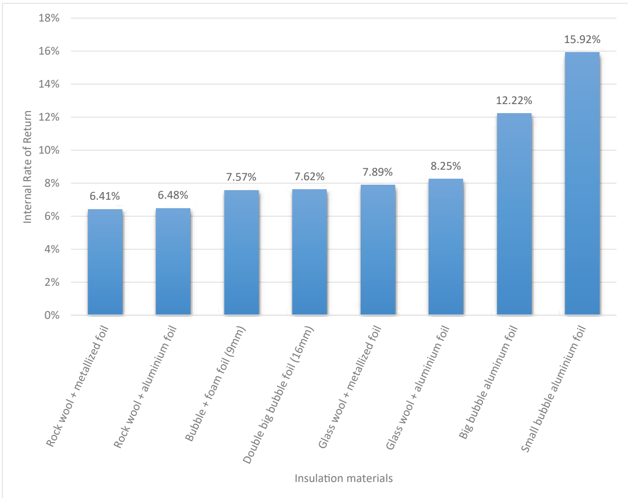

Fig. 6. Ranking of roof insulation systems according to IRR

IV. Conclusions

In this paper, commonly used thermal insulation systems for a hypermarket roof in Malaysia were evaluated from the economic perspective. Three widely used economic evaluation methods which take into consideration time value of money i.e. LCS, DPP and IRR have been used. Results from these three evaluations agreed quantitatively that choosing small bubble and big bubble aluminium foil as the thermal insulation solutions is the best and second best most cost-effective measures. Investing in these two solutions will each generate greater return while having shorter payback period relative to the other examined alternatives. Finally, choosing the effective thermal insulation solution for building in equatorial climate is crucial from socio-environmental perspective as reduction of air-conditioning for cooling will directly decrease CO_2 emissions.

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