Maximization of Energy saving and Minimization of Insulation Cost in a Tropical Hospital: A Case Study in Malaysia

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Abstract:-Equatorial region's climate urges people to use more air conditioners for making cool and dry weather. High consumption of energy by air conditions is the main barrier for reaching energy efficiency in these countries. In any building, most thermal transaction is between external walls and roof of the building. Of course, selection of insulation material and determination of its optimum thickness is one of the prime solutions in energy efficiency in retrofitting projects. The aim of this study is to analyse the energy performance of a hospital in equatorial regions which is working 24 hours per day and 7 days a week and 365 days a year. In this study, for calculating energy consumption, the proposed building was modeled in IESVE software and energy consumption for different insulation material and variety of their thickness was simulated. To find the optimum thickness and material, net saving cost over different lifetime periods was calculated. Polystyrene and mineral wool are two kinds of common and available insulations that were selected as the material options. According to the results, mineral wool is a better material than polystyrene for external walls insulation and also it is found that the optimum thicknesses of mineral wool over 5, 10 and 20 year life times are 4 cm, 8 cm and 10 cm respectively. It is hoped that the result of this research be extended to other hospitals and service buildings in tropical area.

Keywords: wall insulation, optimum insulation thickness, energy cost savings, retrofitting

1 Introduction

In order to increase the fuel price, growing scarcity of fossil fuels and also intensification of CO2 emission in environment the demand of energy is increasing seriously. In this situation, energy consumption cannot be avoided but we can lead it toward more efficient energy by using different techniques. On the other hand, due to the growing global demand of energy, energy efficiency of buildings is needed for safeguarding energy resources for the next generations.

In this regard, equatorial countries need energy for their active air conditioners depending on their geographical situations. It is evident that saving energy in this region has a tight connection with using less cooling and drying systems.

With a population of 27 million people, Malaysia is one of these countries located in a tropical climate [1]. The design of traditional buildings is an architectural solution for combating with hot weather through creating ventilation and wind inside of constructions [2]. Although this solution is working for small size and family houses, it is not applicable for large size constructions with special requirements such as hospitals and the other service buildings.

In a hospital building where cooling demands are continuous throughout or 24 hours a day, the benefits of energy saving are even greater than (e.g.) an office building, where cooling demand is intermittent. In a typical hospital, %45 of the energy cost in bills is due to the Heating Ventilation and Air Conditioning (HVAC) system [3].

The thermal performance of insulation is highly influential on hospitals energy demand. According to [4]M.S. Mohsen et al (2001), the insulation of external walls and roofs can increase energy saving up to %77. By increasing energy efficiency strategies, monthly energy cost can be decreased significantly. Furthermore, they cause the reduction in CO2 emission from power plants [5]. Orner (2005) believes that using acombination of different techniques such as glazing, shading, insulation and natural ventilation has the possibility for reducing %43 of electricity [6].

The hospital is a unique function because of its intense demand for energy. The study is regarding implementation of an insulation system for hospitals' external walls.

2 Background of the problem

Lack of energy and fluctuating price of energy carriers urge different governments to encourage people for less consumption or more efficient energy consumption. Increasing energy efficiency is a crucial way for protecting a country from risks of high price of oil and other energy carriers [7]. Despite all attempts, the warm and humid climate in tropical regions forces people to use different types of energy for cooling themselves. Especially in some characteristic services such as hospitals, refreshing air is more desirable.

Malaysia, as a developing country which is facing significant demand for energy, tries to control and conduct the energy consumption toward renewable energies and make it more efficiently [7]. The Malaysian 10th plan insisted to achieve cumulative saving of 4,000 Ktoe in 2015[8]. Before this, Malaysia has been announced the National Energy Efficiency Master Plan (NEEMP) in 2010 which encourages different sectors to attempt for energy saving and reducing carbon emission in Malaysia [9].

Energy saving and energy efficiency can be achieved in many ways, but basically one cannot ignore insulation of buildings[10]. In tropical geography, using air conditioners, ventilation and day lighting are of particular importance. Thus, reduction of using air conditioners is the main strategy of saving energy [11].

3 Optimum Insulation Thicknesses

The value which provided the minimum total cost is an optimum thickness of insulation. The total cost is a sum resulted from total energy expenditure over the lifetime of a building and the total insulation cost. In this system, the main inputs are cooling and heating transmission through a year. The concept of many researches under this issue is degree-days by measuring cooling and heating requirements [12].
There are four different parameters which can affect the optimum insulation thickness:

1. exterior ambient temperature,
2. length of heating period,
3. total working time of the system,
4. the properties of the insulation material heat conductivity,
5. price and economical life[13].

The major conflict under this issue is based on heating and cooling loads [14]. Researchers have different choices; some of them believe in making separate annual heating and cooling loads. Some others calculate the optimum insulation thickness based on both cooling and heating transmission loads. They consider differences in energy costs and energy efficiency for their system [12]. This is not the issue of discussion that making a wall with zero heat loss or zero transmission is neither practical nor economical. The balance point is a break event point between the cost of insulation material and saving [13]. The break event point illustrates the optimum insulation thickness.

In this study, the optimum insulation thickness for a hospital building is indicated by considering the heat conductivity and the cost of insulation material, average temperature in the west of Malaysia, electricity tariff and the other cost related to cooling system.

4 Objectives

In this study, the optimum insulation thickness for a hospital in Malaysia was determined by considering the heat conductivity and price of natural wool and polystyrene, average temperature in the West Malaysia.

The optimum insulation thickness can be different from one area to other area. The colder climates have higher DD values. For external walls in such a cold climates insulation thickness is higher than warmer climate area. Accordingly to increasing the thickness of insulation material the electricity cost for the hospital decreases but insulation cost which here is which can be called *the investment cost*, will increase [13].

The main objectives of this study are as follows:

A) To investigate the thermal performance of two common wall insulations by simulating in IESVE software. IESVE as a software is capable of calculating electricity consumption in the UKM Medical Centre (MC). In this study by using IESVE, researcher tests both types of insulations (Natural wool and Polystyrene) in different thickness.
B) To investigate the optimum insulation material and its thickness. For achieving to optimum insulation material thickness, researcher needs to calculate and analyze different thickness of insulation material base on investment cost.
C) To calculate energy saving $ value per square meter of gross area over different lifetime and thickness. This is important, using different types of insulation how much energy can save in a building. This rate of energy saving is related to insulation thickness and its lifetime, both.

5 Methodology

5.1 Field Study Description

Malaysia is a tropical country with a hot and humid climate which lies in between 1º and 7º north and 100º and 120º east [15].

Malaysia is created from two different peninsular as Western and Eastern part of the country. The Eastern part including Sabah and Sarawak in the same border with East Indonesia and Brunei is exactly on the Equatorial belt. West Malaysia which is including most population and cities in the country takes advantage from tropical rainforest climate.

The case study hospital is located in Western part of Malaysia and near the capital of the country. The "heat conductivity and insulation price" approach was used for determining optimum insulation thickness at this hospital called Hospital Universiti Kebangsaan Malaysia (HUKM).

The Universiti Kebangsaan Malaysia (UKM), Faculty of Medicine was started in 1972. In 1997 Hospital UKM was established as a teaching Hospital (HUKM) located in Cheras, Selangor [16].

The facility department is the three story building in HUKM where is selected for this study. This building is located in the west part of HUKM. Fig.1 taken from "Google earth" illustrates the general view of HUKM and facility department.

Fig.1: General view of HUKM and Facility department.

5.2 The Structure of the Hospital External Walls

Surely in any building most thermal transaction is between external walls and the roof of the building. External walls should be insulated according to outside situation with suitable insulation materials. This insulation's duty is reduced in space heating and space cooling as well as energy use and energy cost. Obviously, increase in insulation thickness increases the cost of building and decrease its thickness needed more energy payment [17].

The hospital external walls can be different depending on the geography and location of building. In this study, the hospital's external wall is constructed by brick which has been covered by plaster from both sides.

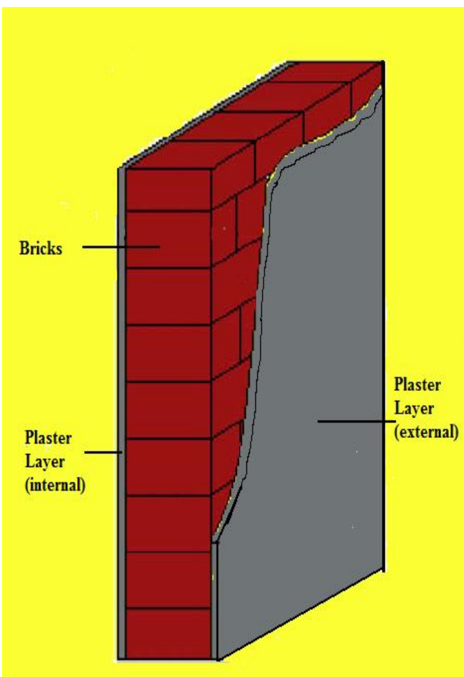

Fig.1 .The material of investigated wall.

The plaster material can be used on plaster layer as internal or on the other side as external layer, too. The structure of external wall is shown in Fig.1.

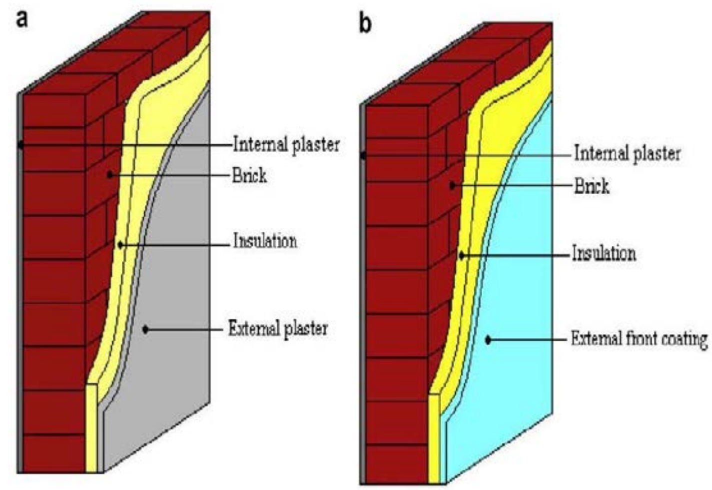

Fig.2 .An external wall with insulation layer [18].

Table.2 and specification of insulation materials is visible in Table. 3.

5.3 Field Study Modelling in Software

The modelled building consists of 3 levels and has a completely air-conditioned floor area. Table 1 shows the specification of this building.

Table 1: Specification of facility department.

NO	Floor	Zones name	Area
1	Basement	Physiotherapy	1871 M^2
2	Ground floor	Lobby-catering area-kindergarten	3056 M^2
3	First floor	Office-praying room	1870 M^2

The modelled building is of standard construction with concrete for structure, bricks for external walls, ceiling tile for ceiling and clay roof tiles for roof material. Fig. 2 illustrates the view of modelled building.

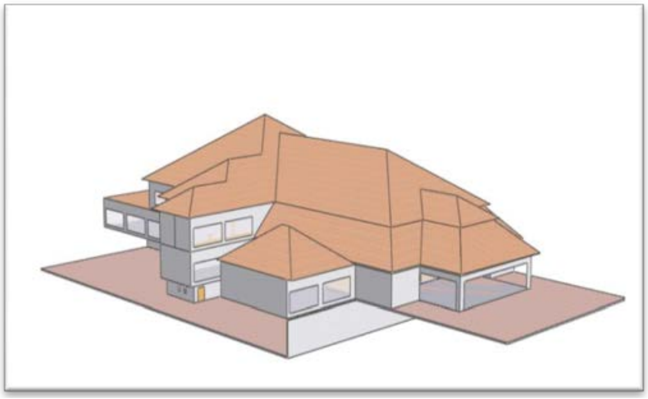

Fig.3: Modeled building in IESVE.

The input data include building construction materials, local climate data which is taken from ASHRAE standard, number of occupancy, internal load, HVAC system data, lighting data, equipment data, etc.[18].

As shown in Table 2external walls in a selected zone are constructed with two layers of plaster and one layer of bricks.

Table2: Material of external walls.

	material	thickness
Out side to Inside	plaster	13 mm
	Brick	114 mm
	plaster	13 mm

In this study, polystyrene and mineral wool are selected as insulation materials at 2, 4, 6, 8 and 10cm thicknesses. Table 3 shows the characteristics of insulation materials which are put in software.

Table 3: Insulation material characteristic.

material	Conductivity w/(m.k)	Density kg/m^3	Specific heat capacity j/(kg.k)
polystyrene	0.040	25	1380
Mineral wool	0.035	30	1000

For finding the optimum of insulation thickness, the influence of different insulation thicknesses on total energy saving cost and net energy saving cost over three lifetime periods is studied.

Nomenclature

A_f	the total insulated area in external walls in m2
C_E	cost of electricity (RM/kWh)
C_i	the cost of insulation in RM per m3
C_{ins}	the total cost of insulation (RM)
C_{TE}	annual energy cost over the life time
E	total annual energy consumption of air conditioner (kWh)
Eq.2	equation for total insulation cost
Eq.3	net energy cost saving
g	inflation ratio in percentage
NS	net energy cost saving in RM
X_{ins}	insulation thickness (m)

Energy rate per kWh is calculated from dividing total annual energy cost in RM by total annual energy consumption in kWh. Energy saving cost is the residuum between energy cost before and after using insulation in lifetime period.

Annual energy cost over the life time is calculated by Eq.1. [7]

$$C_{TE} = C_E . E . \frac{(g+1)^n - 1}{g} . (g+1) \quad \text{Eq.1.}$$

Where C_E is the energy cost in RM/kWh and E is total annual energy consumption in kWh and g is inflation ratio in percentage. The equation for total insulation cost (Eq.2) and net energy cost saving (Eq.3)are defined as:

$$C_{ins} = C_i . A_f . X_{ins} \quad \text{Eq.2}$$

$$NS = (C_{TEun} - C_{TEins}) - C_{ins} \quad \text{Eq.3}$$

Where C_{ins} is the total cost of insulation and C_i is the cost of insulation in RM per m^3 and A_f is the total insulated area in external walls in m^2 and X_{ins} is the insulation thickness and NS is net energy cost saving in RM.

In each lifetime period, the optimum thickness is the maximum amount of net saving in different insulation thicknesses. It means that during that period of time it has a maximum payback.

Furthermore, the comparison between polystyrene and mineral wool has been conducted over each lifetime period. Hence the optimum thickness and material of insulation have been determined according to the net saving energy cost.

For calculating Eq (1), it is necessary to mention that we assumed the Energy Cost is 0.31 RM/kWh. Inflation rate at this research has been assumed %4. This inflation rate only belongs to annual increasing price in electricity tariff. The life cycle of insulation material is considered 5, 10 and 20 years. The cost of insulation has been calculated according top rises in 2011 which is 202 RM/m^3 for polystyrene and 210RM/$m^3$for natural wool. Also, installation cost, maintenance cost, rate of interest for investment amount and interest rate of saving resulted from less payment after insulation has not been considered.

6Analysis and Discussion

6.1 Net Saving Value Over 5 Years

Fig.3 shows the trend lines of total energy saving cost, insulation cost and net saving value calculated for polystyrene.

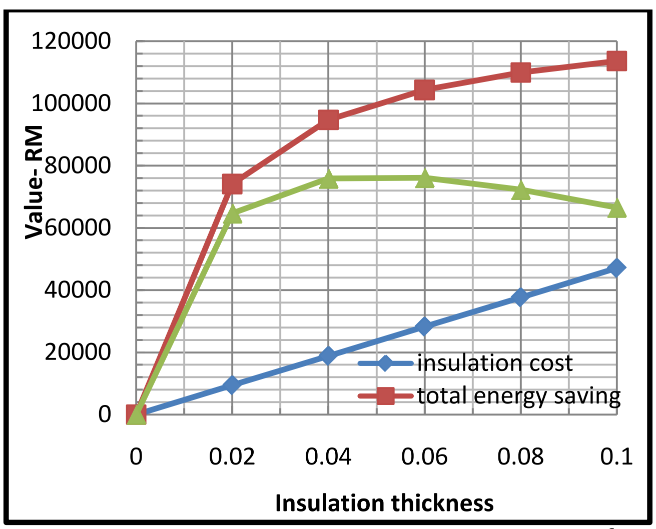

Fig.2: Net energy cost saving over 5 years for Polystyrene.

In These figures, the value of total energy saving increases with accelerating slop until 0.02m of polystyrene thickness but after this point, the acceleration of value decreases point by point. But the polystyrene cost with a constant slop is increasing.

As Fig. 3 illustrates the net saving value scales up when the thickness of insulation increases up to 6cm, therefore over a 5-year-lifetime period, the maximum value of net energy cost saving is at 6 cm thickness. As shown in Table 3 by installing Polystyrene with 6cm thickness, $4.01per square meter of gross floor area is saved over 5 years.

Fig. 4 shows the net saving value for mineral wool in different thicknesses. As Fig.4 Shows, the maximum value of net saving cost is at 4 cm thickness or according to Table 4 is equal to 4.14 $\$/m^2$.

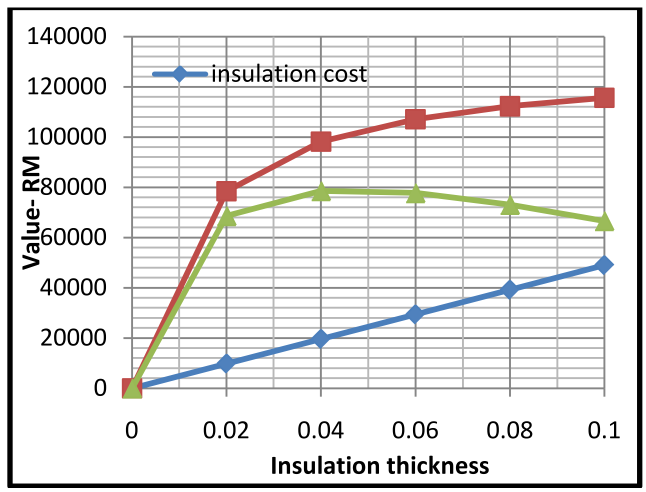

Fig.3: Net energy cost saving over 5 years for mineral wool.

By a comparison between fig. 3and Fig. 4,it is concluded that in a 5-year-lifetime period, the optimum insulation and thickness is mineral wool with 4 cm thickness.

Both of the above figures confirm that although insulation cost and total energy saving increase, net saving decreases after reaching to a margin thickness.

6.2 Net Saving Value over 10 Years

As it is shown in Fig. 5, net energy cost saving trend line reaches to the maximum in 8cm thickness of insulation. According to Table 3, the total net saving value is RM 206,185, or 10.86 $\$/m^2$.

Fig. 6 shows the net saving value for mineral wool in different thicknesses over 10-year lifetimes, the maximum value of net saving is in 8cm thickness with 209,708 RM saving cost value or 11.04 $\$/m^2$.

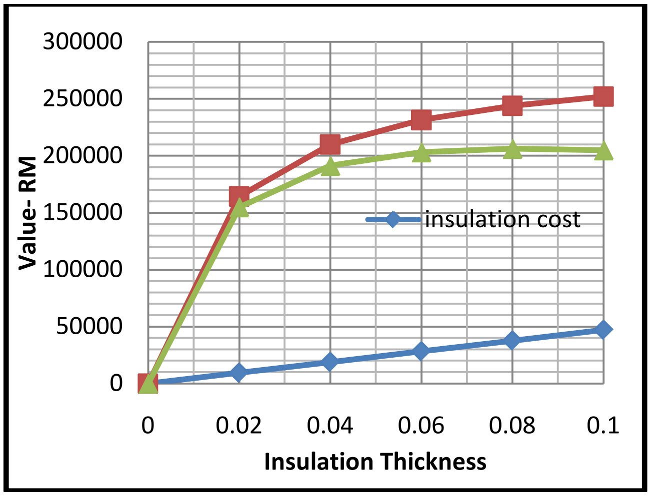

Fig.4: Net saving cost in 10 year for polystyrene

As visible in the above Fig. 5, the gap between polystyrene cost (blue line) and total energy saving (red line) for a 10-year period is bigger than the 5-year period. It shows that with increasing in thickness of polystyrene and period, the energy saving increases significantly.

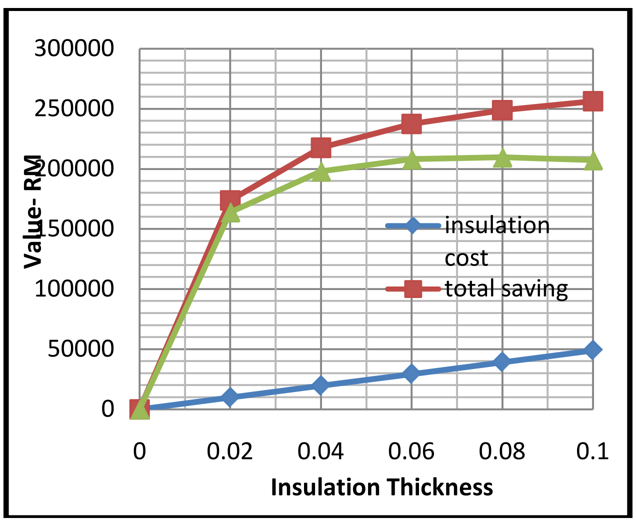

Fig.5: Net saving cost over 10 years lifetime for mineral wool

Comparison of the results shows that mineral wool with 8cm thickness is optimum in 10-year lifetimes.

6. 3 Net Saving Value over 20 Year

The same calculations were done over 20-yearlifetimes for both material-polystyrene and mineral wool. The results are shown in Fig.7 andFig.8 respectively.

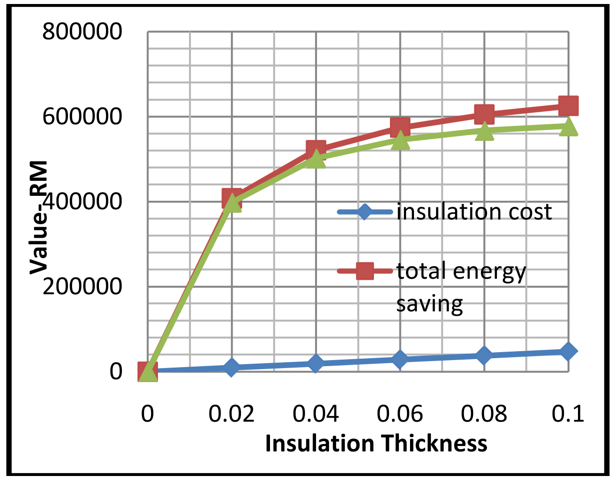

Fig.6: Net saving cost over 20 years lifetime for polystyrene

The maximum value of net saving cost in both materials is in10 cm thickness. It means for a 20-year period with increasing thickness of polystyrene and natural wool the net saving does not has any milestone before 10cm. Maybe its milestone locates in more thickness after 10cm which is not in our research limitation.

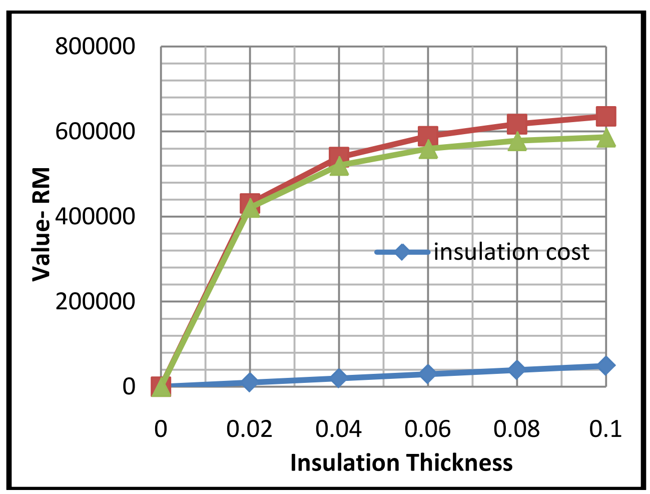

Fig.7: Net saving cost over 20 years lifetime for

As it is extracted and collected in table 3, if the building has been planed only for 5 years, the optimum insulation thickness which has the most energy saving is the natural wool in 4cm thickness. If the construction has been designed for 10 years work, the best insulation would be mineral wool. The thickness is natural wool is 8cm. For a 20-year planning for a building between natural wool and polystyrene and between 0-10cm thicknesses, the best insulation thickness is 10cm natural wool.

Table 3: Net saving cost over different period of lifetime and different insulation thickness for Polystyrene.

Insulation thickness / lifetime	2 cm		4cm		6cm		8cm		10cm	
	Net saving value									
	RM	**$/m2**	**RM**	**$/m2**	**RM**	**$/m2**	**RM**	**$/m2**	**RM**	**$/m2**
5 years	64,715	3.41	75,903	4.00	***76,134***	***4.01***	72,323	3.81	66,567	3.51
10 years	154,918	8.16	191,185	10.07	203,164	10.70	***206,185***	***10.86***	204,893	10.79
20 years	398,187	20.97	502,088	26.44	545,752	28.74	567,195	29.87	***577,944***	***30.44***

It is necessary to mention that the10-year period is double time of 5 years but the amount of energy saving between 5 years to 10 years increases more than 2 times. It is the same situation when we compare the amount of energy saving for 10 years and 20 years. The value of energy saving increases with an accelerated speed.

For example the value of energy saving for 6cm polystyrene for a 5-year period is 4.01$/m^2, for a 10-yearperiod is 10.70$/m^2 and for a 20-year period, it is 28.74$/m^2 .

Table 4: Net saving cost over different period of lifetime and different insulation thickness for mineral wool.

Insulation thickness / lifetime	2 cm		4cm		6cm		8cm		10cm	
	Net saving value									
	RM	**$/m2**	**RM**	**$/m2**	**RM**	**$/m2**	**RM**	**$/m2**	**RM**	**$/m2**
5 years	68612	3.61	***78556***	***4.14***	77747	4.09	73093	3.85	66629	3.51
10 years	164010	8.64	197974	10.43	208103	10.96	***209708***	***11.04***	207301	10.92
20 years	421290	22.19	520033	27.39	559659	29.48	578144	30.45	***586678***	***30.90***

As it is shown in Table 4, the maximum net saving cost is RM 586,678 or 30.90 $/m^2. Therefore, mineral wool with 10cm of thickness is the optimum insulation for external walls. As an interim summary; lifetime has a direct relation with the thickness of polystyrene and natural wool. In other words, the more lifetimes needs more thicknesses.

For comparing the energy usage of building to other, building energy index (BEI) is introduced.BEI is usually expressed as kWh/m2/year which shows amount of total energy usage for one year in building in kilo Watts hours which is divided by the gross floor area of building in square meters [19]. Saving Building Energy Index (BEI) by applying different thickness and materials is shown as below:

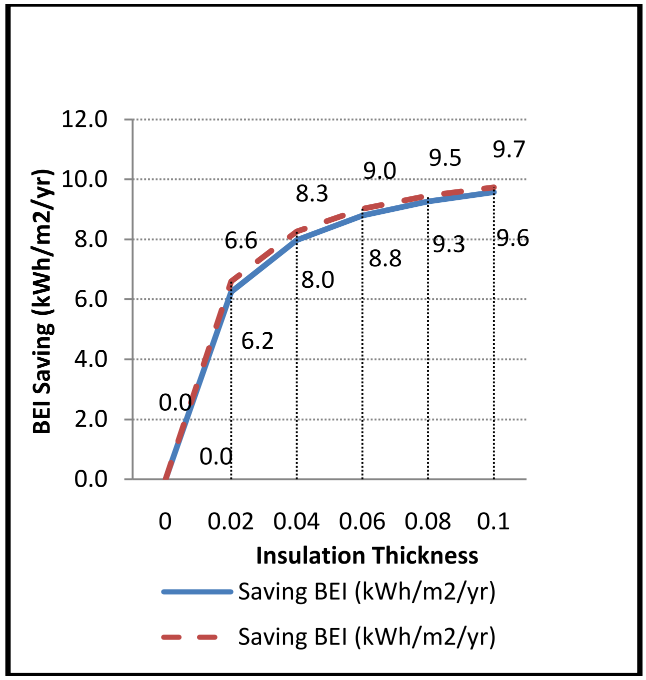

Table 5: Building Energy Index (BEI)[20]

Insulation material	Thickness	0	0.02	0.04	0.06	0.08	0.1
Polystyrene	Saving BEI (kWh/m^2/yr)	0.0	6.2	8.0	8.8	9.3	9.6
Rockwool	Saving BEI (kWh/m2/yr)	0.0	6.6	8.3	9.0	9.5	9.7

7 Conclusions

As it was expected, finding maximum saving in energy and minimum thickness of insulation in the under survey hospital is related to many different factors. There is a significant correlation between lifetime and thickness and also a direct relation between them. This direct relation has been calculated for both mineral wool and polystyrene in different thicknesses and according to different lifetimes. The result of optimum thickness of insulation and net saving shows that by increasing the lifetime period, the optimum thickness of insulation grows up. It means that the age of insulation has a direct relation with the thickness of insulation. Compared with polystyrene; the mineral wool has the optimum material for insulating hospital external walls. It is necessary to mention that the comparison in this study is only between the mineral wool and polystyrene and maybe some other materials have more efficiency and optimum material for insulating the mentioned external walls. The maximum value of net saving energy cost in 5, 10 and 20 years lifetime are RM 78,556, RM 209,708 and RM 586,678 respectively. Also, it is visible in other wise 4.14 $\$/m^2$, 11.04$\$/m^2$and30.9$\$/m^2$. It is hoped that this study can introduce a practical solution for saving energy and increasing the energy efficiency in Malaysian hospitals. The researchers believe that this study and its final solution are applicable in other tropical countries and extendable to other types of buildings, too.

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