THERMAL INSULATION CONSIDERATION IN BUILDING AND ITS EFFECT ON THE ANNUAL ELECTRICITY AND FUEL CONSUMPTION AND COST

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ABSTRACT

This research is to estimate the amount of annual heat lost/gained through external walls which are different in their insulation envelope and to compare it with the annual heating/cooling loads needed to keep a convenient indoor temperature. The cost of heating /cooling loads was also estimated for each wall using Life Cycle Cost Analysis (LCCA). During summer, electrical energy was assumed to provide the cooling load while in winter kerosene fuel was assumed to supply heating load in order to give diverse calculations of energy consumption /cost.

The data in this research was taken in Maysan Province during the winter of 2013/2014 and summer of 2014. The results show that regarding all aspects, a wall with an insulation envelope (internal or external) is always advantageous over the one without insulation. The calculations and demonstrations show also a considerable save in annual cost per square meter of external wall with thermal insulation compared to the one without thermal insulation.

Key words: thermal insulation, annual heat gain, annual heat loss, annual heating load, annual cooling load, LCCA, annual cost of electricity, annual cost of fuel.

الخلاصة

في هذا البحث تم حساب الحمل و الخسارة في الحرارة المارة خلال جدارن خارجية تختلف بطريقة عزلها الحراري ومن ثم مقارنتها مع حمل التبريد او الحرارة الواجب تجهيزها لغرض الحفاظ على درجة حرارة داخلية ملائمة. تكاليف الحمل الحراري او حمل التبريد تم حسابة من خلال ما يسمى بتحليل الكلف لدورة الحياة. حمل التبريد المجهز في فصل الصيف تم افتراضة انه يتم باستخدام الطاقة الكهربائية بينما خلال الشتاء تم افتراض وقود الكيروسين هو المصدر المجهز للحمل الحراري وهذا الامر يعطي تنوع في حسابات استهلاك الطاقة وكلفها.

البيانات في هذا البحث تم اخذها خلال شتاء ٢٠١٤/٢٠١٣ وصيف ٢٠١٤ في محافظة ميسان. النتائج بينت أن الجدار الخارجي المجهز بعزل حراري (داخلي كان او خارجي) يتميز بجميع النواحي على الجدار الغير مجهز بالعزل الحراري. النتائج بينت كذلك ان هناك توفير معتبر في تكاليف الطاقة الكهربائية والوقود المستهلك خلال العام بالنسبة للجدار ذو العزل الحراري مقارنة مع الجدار الغير معزول حرارياً.

كلمات الدلالة: العزل الحراري، الحرارة المكتسبة سنوياً، الحرارة المفقودة سنوياً، الحمل الحراري السنوي، حمل التبريد سنوياً، تحليل الكلف لدورة الحياة، الكلفة السنوية للطاقة الكهربائية، الكلفة السنوية للوقود.

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NOMENCLATURE

$\dot{Q}$ = the overall heat transfer rate (W)

U = the overall heat transfer coefficient (W/m^2.K)

A =heat transfer area (m^2)

ΔT = overall temperature difference = $(T_{\infty2} - T_{\infty1})$, if $T_{\infty2} > T_{\infty1}$

$T_{\infty1}$ = indoor temperature (K)

$T_{\infty2}$ = outdoor temperature (K)

R_1 = internal plaster thermal resistance = $\frac{L_1}{k_1}$

R_2 = brick wall thermal resistance = $\frac{L_2}{k_2}$

R_3 = external plaster thermal resistance = $\frac{L_3}{k_3}$

$R_{\infty1}$ = internal convective resistance = $\frac{1}{h_1}$

$R_{\infty1}$ = external convective resistance = $\frac{1}{h_2}$

R_w = thermal resistance of wooden board = $\frac{L_w}{k_w}$

R_p = thermal resistance of polystyrene layer = $\frac{L_p}{k_p}$

R_r = thermal resistance of glass wool layer = $\frac{L_r}{k_r}$

R_t = thermal resistance of metal tile = $\frac{L_t}{k_t}$

k = thermal conductivity of insulation (W/m.K)

h = convective heat transfer coefficient (W/m^2.K)

T_b = Balance Temperature

η = the efficiency of heating system

COP = coefficient of performance of the cooling system

$C_{t,ins}$ = total cost of insulation (in US$)

$C_{ins}x$ = cost of insulation materials (in US$)

C_{inst} = cost of installation for insulation materials (in US$)

C_H = annual heating cost (in US$)

C_C = annual cooling cost (in US$)

C_f = the cost of fuel (in US$/m^3)

C_e = the cost of electricity (in US$)

H_u = the lower heating value of the fuel (in J/m^3)

1. INTRODUCTION

Despite the high importance of thermal insulation in buildings, there are few Iraqi people who consider thermal insulation upon planning for new buildings. The reason could be the ignorance of energy conversation in Iraqi daily life because of the low cost of energy people pay (if there is any) especially for electrical power. However, thermal insulation consideration should be taken in account through the coming building plans because the future of energy is becoming more and more ambiguous. Moreover, the additional cost arisesfrom using thermal insulation cannot be compared to the benefit ofsaving in electricity and fuel fees, life comforting andbeautiful decoration.

The four main sectors that consume energy are: industry, commercial and residential premises, transportation and agricultural. Because of population growth, commercial and residential premises represent the highest sector among others in energy consumption. This growth in population causes more areas and buildings to be occupied by people and hence more energy to be consumed. This consumption in energy (fuel and electricity) is needed in order to keep a convenient indoor temperaturesince the energy is lost through a building from different ways; external walls, celling, floor, windows and air ventilations.

In this research, there will be a focus on the energy loss through external walls only because; first in order to limit the scope of research within the most important parameters. Second, the fact that the analysis applied for walls can be also applied to ceilings, floor and windows with minor differences. In addition, there will be three types of external walls under consideration (all built with burned clay bricks); one without thermal insulation, the other with an internal insulation and the third with an external insulation.Then, the energy loss and the amount of energy consumed in order to keep a convenient room temperature are compared to each other for each wall.

Nevertheless, the heat loss cannot always give a clear idea about the amount of energy needed for keeping a convenient indoor temperature because it depends on the difference between indoor and outdoor temperatures. Therefore Life Cycle Cost Analysis (LCCA) will be applied for the calculation of energy in order to obtain the correct amount and cost of energy needed per square meter for each case study.

2. LITERATURE REVIEW

Energy conservation is an increasingly important issue for the residential sector, which accounts fora substantial share of global energy demand. Thermal insulation appears to beone of the most valuable tools in achieving energy conservation in buildings and determining theeconomic thickness of insulation materials used in building envelopes has become the main goal ofmany investigations. For this reason, numerous studies have been conducted to optimize the thermalinsulation thicknesses based on degree-days analysis. Below some of the most relevant studies are listed in order to give the reader a basic idea about the scope of this research.

Turki and Zaki[1] investigated the effect of insulation and energy storing layers upon the cooling load. A mathematical model to study the thermal response of multilayer building components was presented. Farhanieh and sttari [2] studied the effects of insulation on the energy saving in Iranian building. For this purpose, an integrative modeling was used for simulation of energy consumption in buildings. Bakos [3]evaluated the energy saving by comparing the energy consumption (in KWH) for space heating before and also after the application of thermal insulation in the structure envelope. A performance comparison like concerning cost and energy saving was studied. Sofrata and Salmeen [4] developed a consistent and more general mathematical model for optimum insulation thickness. They also introduced a program flowchart to select the best insulation thickness. In their study, the life-cycle cost analysis (LCCA) was used to calculate the costs of heating over the life time. Mohammed and Khawaja [5] determined the optimum thickness of insulation for some insulating materials used in order to reduce the rate of heat flow to the buildings in hot countries. Important factor that affects the optimum thickness of insulation is the solar radiation energy flowing into the house. In this research, a solar radiation calculation was made. Lollintet. al[6] demonstrated the significant economic advantages come out from high-performance building envelope. In this paper, economic analysis and evaluation of the envelope components were based on the optimization of the insulating materials thickness. Mohsen and Akash[7] evaluated the energy conservation in residential buildings in Jordan. This paper was intended to provide some insights into the general state of energy consumption in the residential sector and its trends in Jordan. Dombayci [8] investigated the environment impact of optimum insulation thickness. In this research, coal was used as the fuel source and Expanded Polystyrene (EPS) as insulation material. Mahliaet. al. [9] developed correlation between thermal conductivity and the thickness of selected insulation materials for building wall. Lu et al. [10] developed a new analytical method, which provides close-formed solutions for both transient indoor and envelope temperature changes in building. Time-dependent boundary temperature is presented as Fourier series.

Dylewaski and Adamczyk[11] presented several types of thermal insulation in order to find out the best ones in respect to economic and environmental considerations. Ozel[12] studied thermal performance and optimum insulation thickness of building walls with different structure materials under dynamic thermal conditions. It was found that the energy saving gain would depend on the thickness of insulation and different structure materials of the walls studied. The research was done in Turkey.

The scope of this research is a comparison between three kinds of walls; the first has no thermal insulation on both sides. The second has an internal thermal insulation which consists of wooden board and a layer of polystyrene. The third has an external thermal insulation which consists of metal tiles and a layer of glass wool, see figure (1). These three kinds of wall are common in Iraq and the comparison will not be restricted to the calculation of heat loss (or heat gain in summer season) from each one but also the amount and cost of energy required to keep a convenient room temperature will also be calculated per square meter using LCCA.

Figure (1): A building in Maysan Province covered with metal tiles

During winter, it was assumed that heating is made by burning fuel (namely kerosene heaters) even though electrical heaters nowadays are more common in Iraq than kerosene heaters. However, the aim of research is to cover a diverse range of energy consumption as it is previously mentioned, the future of energy is not so optimistic that many things may be changed in energy consumption sectors within the coming few years.

During summer however we assume that cooling is made by air conditioners (i.e. electrical energy). The cost of electrical unit (kWh) was adopted from the electricity bills issued by electricity distribution directorates. This price (for sure) will be higher within the next few years!

3. THEORETICAL ANALYSIS

Consider a composite wall with threelayers(internal plaster, brick, external plaster) as an example of a conventional wall without thermal insulation, see figure (2) below. The individual layer thicknesses and thermal conductivities are L_1, L_2, $L_3$and k_1, k_2, k_3 respectively. The heat transfer area, which is perpendicular to the direction of heat transfer, is the same (A) for each layer. Assume the wall boundaries are in convectionheat to the environment on both sideswhich are at $T_{\infty 1}$ and $T_{\infty 2}$ respectively.Convective heat transfer coefficients are h_1 and h_2.

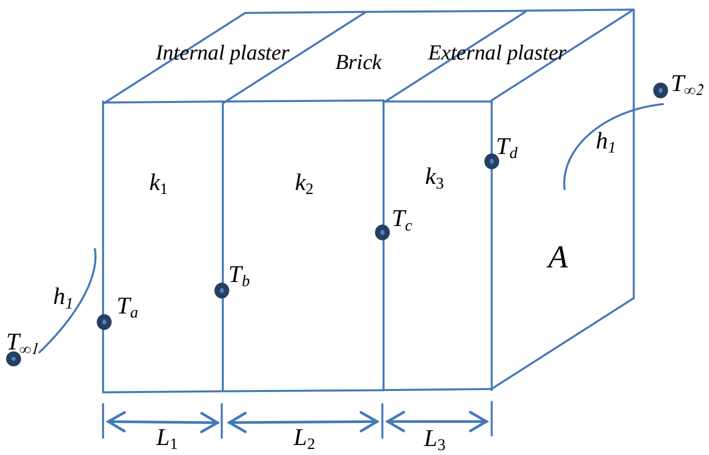


Figure (2) Schematic diagram for a composite wall (without insulation)

The overall gain in heat transfer through the wall (or loss if the outdoor temperature $T_{\infty 2}$is lower than the indoor temperature $T_{\infty 1}$) can be expressed as follows, J. P. Holman[13]:

$$\dot{Q}_{\frac{loss}{gain}} = UA\Delta T \tag{1}$$

Overall heat transfer coefficient (U) can be expressed as follows:

$$U_{no\ insulation} = \frac{1}{R_{\infty 2} + R_3 + R_2 + R_1 + R_{\infty 1}} \tag{2}$$

This seems to be so similar to the electrical circuit, in which there are electrical resistances, electromotive force and current, see figure (3). Here the electrical resistances are replaced by thermal resistances, electromotive force is replaced by the overall temperature difference (driving force) and current is replaced by the rate of heat transfer.

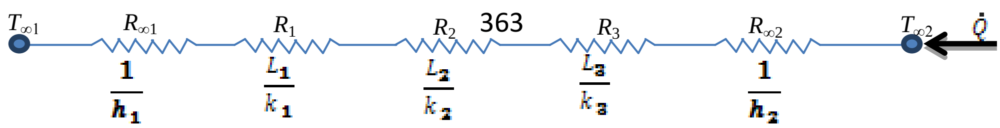
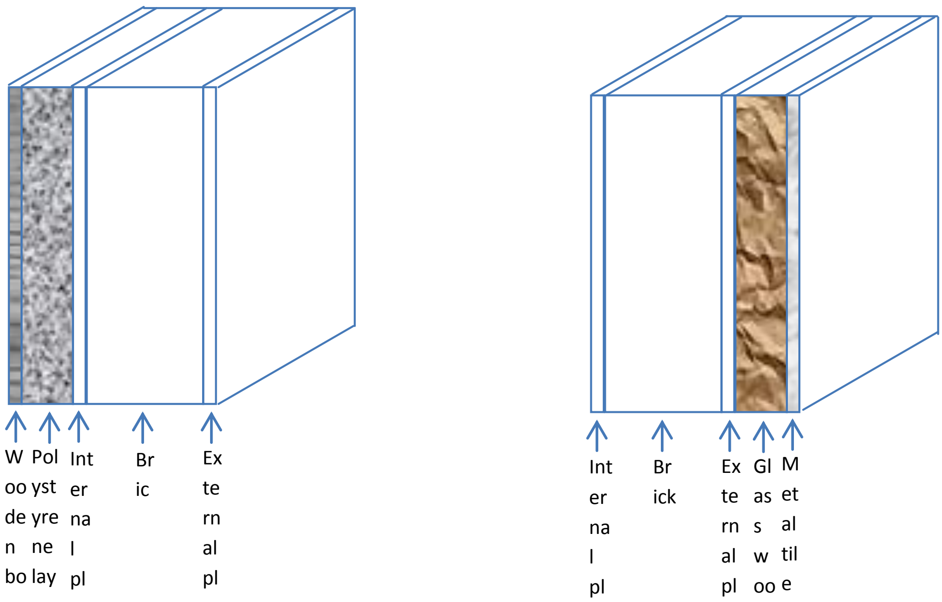


Figure (3) Electrical analogue of heat transfer through the composite wall shown in Figure (2)

It should be noticed that adding thermal insulation layers (external or internal) will result in two more thermal resistances, see Figure (4)



(a) (b)

Figure (4) A plane wall with internal insulation (a)
A plane wall with external insulation (b)

In this case, the overall heat transfer coefficient (U) is expressed as follows:

$$U_{internal\ insulation} = \frac{1}{R_{\infty1} + R_w + R_p + R_1 + R_2 + R_3 + R_{\infty2}} \quad (3)$$

$$U_{external\ insulation} = \frac{1}{R_{\infty1} + R_1 + R_2 + R_3 + R_r + R_t + R_{\infty2}} \quad (4)$$

Before proceeding to the next section, it is significant to mention that optimum insulation thickness calculations are normally advisable for the complete design. However, it is not applied in this research because "optimum" means the maximum insulation and minimum cost of thermal insulationmaterials. Nonetheless, the commercial insulation materials used in this research are the ones found in local markets. Reducing the thickness to its optimum dimension may result in an increase in the cost of insulation because it needs extra fee for thickness reduction. Therefore, the minimum thickness of polystyrene board found in market is 2.5 cm and for glass wool layer is 5 cm. the optimum thickness however can be obtained from the equation below:

(5)

4. LIFE CYCLE COST ANALYSIS (LCCA)

Since the optimum thickness of insulation is not considered in this research, the LCCA will be applied only for calculating annual cooling cost (US$/kWh of electricity) during three months of Summer (JUNE, JULY, AUGUST)andannual heating cost in (US$/liter of fuel) during Winter (DECEMBER, JAUNUARY, FEBRUARY). The following mathematical model was adopted based on the one found in O. Kaynakli [14]:

One of the methods to estimate the amount of energy required for heating and cooling a building is to calculate heating and cooling degree-days (HDDs & CDDs)using the following formula:

$$CDD = \sum_{days} (T_{\infty 2} - T_b)^+ \qquad (6)$$

$$HDD = \sum_{days} (T_b - T_{\infty 2})^+ \qquad (7)$$

The plus sign in the above formulas indicates that only positive values are to be calculated. The number of degree-days (DDs) is the sum of differences between the balance temperature T_b and the daily average outside air temperature.

The annual heating and cooling loads per unit area of external wall are given as follows:

$$q_H = 2160\ HDD \frac{U}{\eta} \qquad (8)$$

$$q_c = 4320\ CDD \frac{U}{COP} \qquad (9)$$

The cost of insulation used on an external wall is a function of its thickness. Thus the total insulation cost including the cost of installation is given by:

$$C_{t,ins} = C_{ins}x + C_{inst} \qquad (10)$$

The annual heating and cooling costs are given by:

(11)

(12)

5. CALCULATION AND RESULT

Table (1) lists the numerical data for the building and insulation materials used in the three types of wall, M. Warren, et. al, [15]. It should be emphasized that some of the values especially those refer to the cost of insulation andinstallation per square meters are roughly estimated.

Table (1) numerical data for materials used in research

Building and insulating Materials	**Thickness (mm)**	**Thermal conductivity (W/m. K)**	**Thermal Resistance (m2. K/W)**	**Cost (US$/m2)**	**Installation cost (US$/m2)**
Wooden board	5	0.15	0.034	5	25
Polystyrene board	25	0.038	0.657	1	10
Glass wool layer	50	0.078	0.641	3	30

Metal Tiles including Plastic layer	2		0.0017	20	70
Burned clay Brick	250	1.6	0.156	……..	………..
Internal Plaster	10	0.6	0.0167	…………	………..
External Plaster	10	1.7	0.00588	………..	………….

The value of overall heat transfer coefficients (U) for each type of wall during summer months are listed in table (2)

Table (2) the value of overall heat transfer coefficients

Wall Type	h_1 **(W/M2. K)**	h_2 **(W/M2. K)**	$T_{\infty 1}$**(°C)**	$T_{\infty 2}$**(°C)**	U **(W/M2. K)**
Without insulation	10 – 25	50 - 80	28 - 40	42 - 54	3.349– 4.327
Internal insulation	10 – 25	50 - 80	23 - 32	42 - 54	1.01– 1.084
External insulation	10 – 25	50 - 80	22 - 30	42 - 54	1.062– 1.144

The corresponding annual heat gain, cooling load and cooling costs are listed in table (3). The cost of electricity unit (kWH) is 10 Iraqi Dinar (≈0.01 US$) and the $COP$for cooling devices is 2.5.The balance temperature T_b is 42 at peak outdoor temperature $T_{\infty 2}$. This means the average value of CDD is 12.

Table (3) annual heat gain, cooling loads and annual costs for each wall

Wall Type	U **(W/M2. K)**	**Annual heat gain kW/m2**	**Annual cooling load kW/m2**	**Annual cooling cost US$/m2**
Without insulation	3.547 – 4.327	101,279–130,863	69,448–89,735	694.48 – 897.35
Internal insulation	2.453 – 2.940	41,472 – 51,535	20,954 – 22,488	209.54 – 224.88
External insulation	2.498 – 3.004	45,894 – 59,328	22,029 – 23,731	220.29 – 237.31

The above table shows that an annual save of US$ 672.46 / m^2 will be gained from using internal insulation and US$ 660.03/ m^2 from using external insulation.

The value of annual heat loss, heating load and heating cost during winter months are listed in table (4).For the calculation of heating loads and costs we need the following data: The balance temperature T_b is 17 at lowest outdoor temperature $T_{\infty 2}$. This means the average value of HDD is 7, the cost of fuelC_f is (200 US$/m3) and the lower heating value of kerosene is (3.726X10^{10} J/m^3). The efficiency of kerosene heater was assumed 90%.It should be noticed that when the outdoor temperature risesabove the indoor temperature (or becomes equal), the value of HDD was set to zero.

Table (4) the values of heat losses, heating loads & heating costs for each wall

Wall Type	$T_{\infty 1}$(°C)	$T_{\infty 2}$(°C)	Annual heating loss kW/m2	Annual heating loadkW/m2	Annual costUS$/m2
Without insulation	20 - 25	10 - 23	72,342-18,694	7,702– 5,623	29.93 - 8.04
Internal insulation	23 - 27	10 - 23	28,375-9,370	1,6976 - 0.812	13.05 – 3.75
External insulation	23 - 28	10 - 23	29,831-12,360	1,748 – 0.922	13.80 – 3.96

The above table shows that an annual saving of US$ 16.88/m^2 for the internal insulation and US$ 16.13/m^2 for external insulation.

It ought be well noticed that the above calculations are based on a unit square meter of an external wall. The total area of the external wall within a house will make a remarkable difference in the cost. Nonetheless, there are other losses of energy through windows, ceilings and ventilations which will add an additional cost of energy consumption.

For better demonstration, the data of table (3) for wider ranges of temperatures and coefficient of convection heat during the summer of year 2014 in Maysan Province is shown in Figures (5), (6) and (7)

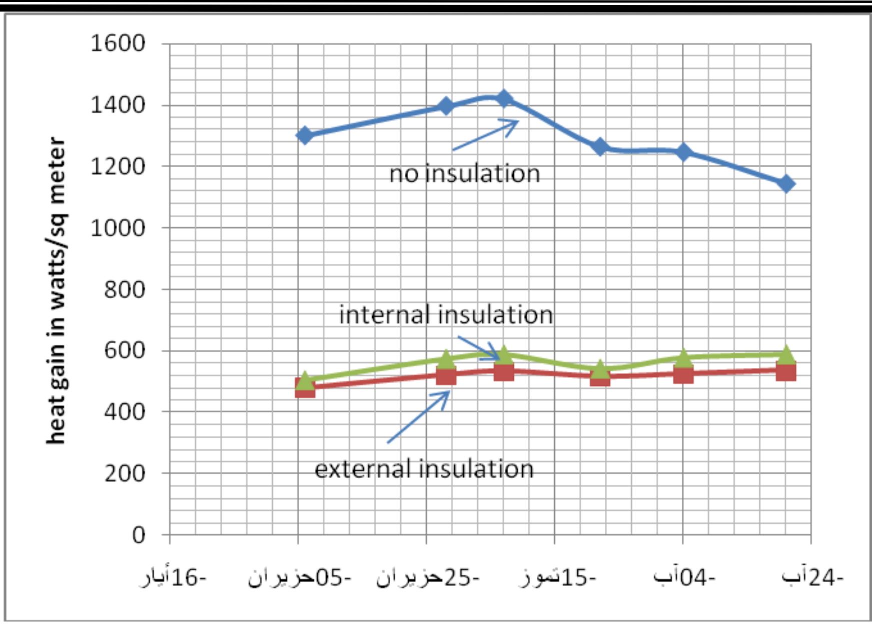


Figure (6) Heat gain during summer season for each wall in W/m2

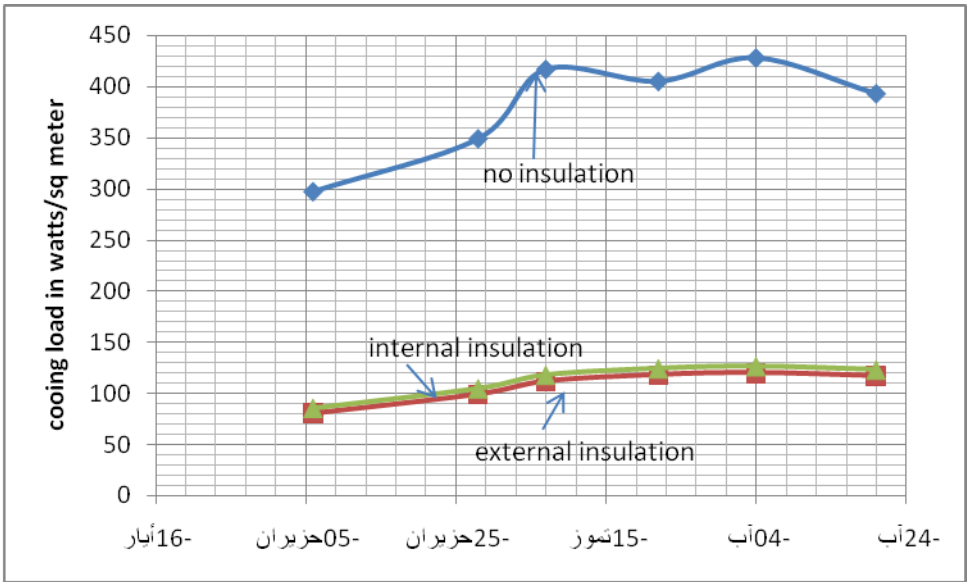


Figure (7) cooling load during summer season for each wall in W/m2

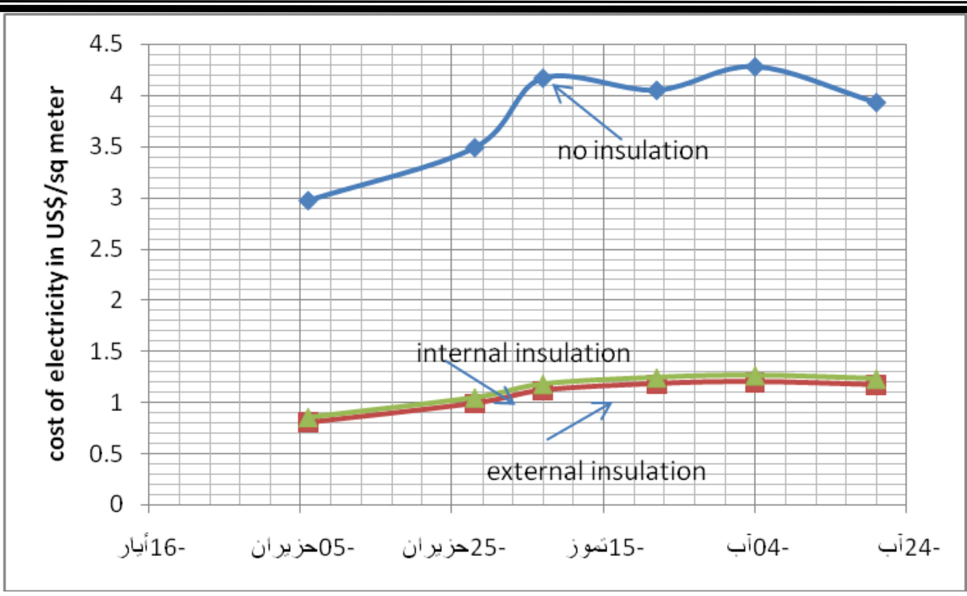


Figure (8) cost of electricity during summer season for each wall in US$/m2

The data in table (4) during the months of winter 2013/2014 is demonstrated in Figures 9-11 through a wider range of temperature and convective coefficient of heat (and *HDD*). As it was previously mentioned for values of HDD that are negative or Zero, the load of heating as well as cost of heating was set to zero.

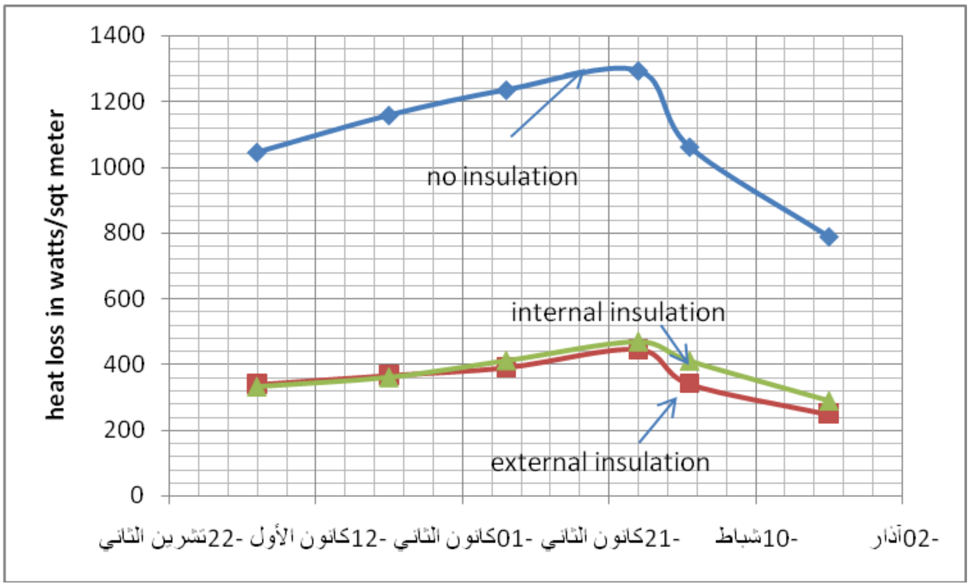


Figure (9) Heat lost during winter season for each wall in W/m2

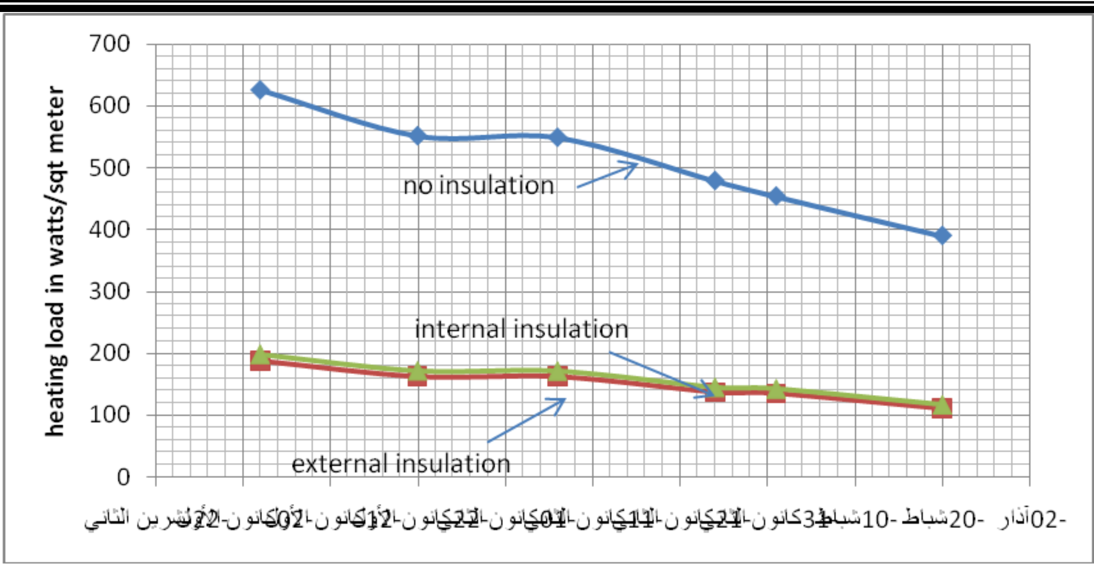


Figure (10) Heating load during winter season for each wall in W/m2

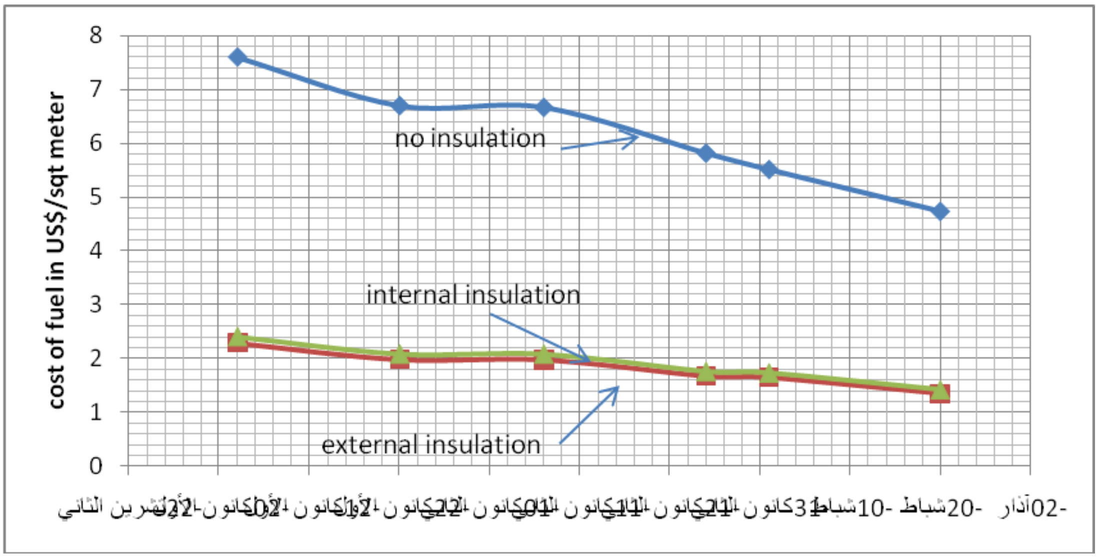


Figure (11) Cost of fuel during winter season for each wall in US$/m2

6. DISCUSSION AND SUGGESTIONS

Based on the calculations and demonstrations, it is obviously noticed that the wall with insulation (no matter whether internal or external) is advantageous over the one without insulation in all aspects; heat gain/loss, heating/cooling loads and heating/cooling cost. Those aspects are of special importance because it is not only restricted to cost but also to the convenience, comforting and decoration of our houses and work offices. Moreover, the cost of installation is calculated once it is installed, then it will not be accumulated. Hence, this cost will not influence the fact that insulated walls will always save money despite how much the installation envelope costs.

The demonstrations also show that regarding the calculations made, the differences between internal and external envelopes can be ignored. Nonetheless, the installation cost for external envelope (glass wool and metal tiles) is higher than the cost of installation of internal envelope (wooden boards and polystyrene layer). Yet the internal envelope cannot be compared with the external one in term of safety. Wood and polystyrene are so inflammable that the external envelope becomes advantageous. In addition, external insulation with metal tiles give the building more elegant, modern look, hence it plays two roles, insulation and decoration.

It should be emphasized that the external envelope which is installed by local people in which there is neither glass wool nor other insulation materials cannot be considered as an external insulation envelope. In this case the metal tiles has a decoration function only because installing the metal tiles without insulation layer beneath will result in many troubles among which: high wind under the tiles which cause rapid heat transfer (negative in all seasons), the empty space beneath the tiles will be a place of rodents which also cause extra troubles, the absence of insulation layer will result in noisy, unstable structure which is unable to withstand high wind, etc.

Finally, the main suggestion is to take insulation in consideration for all coming building planning because this consideration shall save residentsfrom paying too much for energy which represents the vital nerveof our life. In addition, insulation materials nowadays become more and more familiar and available everywhere and offer diverse colors and design; hence they will meet our desire and requirements for decoration and conversation.

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