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Building Thermal Insulation Performance and economic benefits: A Case Study in Libya

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ABSTRACT

Three different insulating scenarios were investigated using Energy-plus software, to study the effect of using expanded polystyrene boards on building energy consumption at the Libyan Center for Solar Energy Research and Studies. The three insulation scenarios with different polystyrene insulation thicknesses and densities were investigated. Polystyrene total cost, Payback period, total and net money saving using insulation, as well as the percentage gain were calculated for each case in the three investigated scenarios for 50 years.

The most money saving scenarios after 50 years is by insulating the building roof and external walls with an average insulation thickness of 7 cm, reaching about 78000 L.D and a tariff of 0.9261 L.D /kWh. While the least money saving is the roof scenario with an insulation thickness of 2.5 cm, reaching more than 29000 L.D and the same tariff. The highest percentage gain values are 76 %, 103 % and1090 % at the roof scenario, 2.5 cm insulation thickness and energy tariffs of 0.15 L.D /kWh, 0.1732 L.D/kWh and 0.9261 L.D/kWh, respectively. While the lowest percentage gain values are about 17.5 %, 35.7 % and 725 % at the wall scenario 10 cm insulation thickness and energy tariffs of 0.15 L.D/kWh, 0.1732 L.D/kWh and 0.9261 L.D/kWh, respectively. the payback period of total insulation cost is significantly dependent on insulation thickness and energy tariff. These results show that low energy tariff (current energy tariff) values economically are not cost effective regarding the payback period. Consequently, prices do not motivate residents to save energy with the use of thermal insulation unless actual energy prices are considered.

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أداء العزل الحراري للمباني والفوائد الاقتصادية: دراسة حالة في ليبيا

فائزة محمد القنين، عبد المجيد عمر القريو، و إخلاص برناز.

ملخص: تمت دراسة ثلاثة سيناريوهات عزل مختلفة باستخدام برنامج Energy-plus لدراسة تأثير استخدام ألواح البوليسترين الممدد على استهلاك الطاقة في المباني بالمركز الليبي لبحوث ودراسات الطاقة الشمسية. تمت دراسة سيناريوهات العزل الثلاثة بسماكات وكثافات مختلفة لعزل البوليسترين. تم حساب التكلفة الإجمالية للبوليسترين وفترة الاسترداد والوفر المالي الإجمالي والصافي باستخدام العزل، وكذلك النسبة المئوية للمكسب لكل حالة في السيناريوهات الثلاثة لمدة 50 عامًا.

أكثر السيناريوهات وفرًا بعد 50 عامًا هو عزل سقف المبنى والجدران الخارجية بمتوسط سماكة عزل 7 سم، حيث بلغ حوالي 78000 L.D وتعريفة 0.9261 L.D / kWh. بينما أقل السيناريوهات وفرًا هو سيناريو السقف بسماكة عزل 2.5 سم، حيث بلغ أكثر من 29000 L.D ونفس التعريفة. أعلى قيم للنسبة المئوية للكسب هي 76٪ و 103٪ و 1090٪ في سيناريو السقف وسمك العزل 2.5 سم وتعريفات الطاقة 0.15 L.D / kWh و 0.1732 L.D / kWh و 0.9261 L.D / kWh على التوالي. في حين أن أقل قيم النسبة المئوية للكسب هي حوالي 17.5٪ و 35.7٪ و 725٪ في سيناريو الجدار بسمك عزل 10 سم وتعريفات طاقة 0.15 L.D / kWh و 0.1732 L.D / kWh و 0.9261 L.D / kWh على التوالي. تعتمد فترة الاسترداد لتكلفة العزل الإجمالية بشكل كبير على سمك العزل وتعريفة الطاقة. تُظهر هذه النتائج أن قيم تعريفة الطاقة المنخفضة (تعريفة الطاقة الحالية) ليست فعالة من حيث التكلفة اقتصاديًا فيما يتعلق بفترة الاسترداد. وبالتالي، فإن الأسعار لا تحفز السكان على توفير الطاقة باستخدام العزل الحراري ما لم يتم النظر في أسعار الطاقة الفعلية.

الكلمات المفتاحية – Energy Plus، البوليسترين، سمك العزل، كثافة العزل.

1. INTRODUCTION

The electric power sector is one of the most important sectors where all economic sectors have become fully dependent on electrical energy. Statistics indicate that there is a significant increase in consumption rates resulting from the use of cooling and heating means. In Libya, the total production capacity in 2012 reached bout 5,981MW with a percentage increase of about 3.85 % from total production in 2010. According to the General Electric Company of Libya (GECOL), the energy consumption of residential and public utilities sectors reached 36% and 13 % in 2012, respectively [1]. Energy consumption in the residential sector in 2021 has increased to 51%, where 15% of consumption is by public utilities [2]. Moreover, the increase in population, and climate change, rationalization of energy consumption has become a civilized requirement for raising energy efficiency. Researchers have investigated different techniques to raise energy efficiency in buildings, including thermal insulation thickness and life cycle cost analysis. Bolatturk (2006-2008) investigated the optimum thickness of building insulation and payback period at different climatic zones as well as cooling and heating degree-hours of the warm zones of Turkey. Results showed that the optimum insulation thickness ranges between 1.6 and 2.7 cm, while energy savings were between 22% and 79%, and payback periods were between 1.3 and 5.47 years depending on the climatic zone [3] [4]. Khalid Askar Al-Shaibani et al. (2014) investigated the performance of thermal insulation on electricity consumption in building using air conditioning. Results showed a reduction in electricity consumption by air conditioning with more than 28%, compared with non-thermally insulated building. This percentage decreases to reach a reduction of about 16% for buildings with a windows area equal to 20% of the building area [5]. Alghoul et al. (2016) investigated the optimum insulation thickness with respect to life cycle cost analysis for building in Tripoli Libya. Results showed that the current energy do not motivate residents to save energy with the use of thermal insulation unless actual energy prices is considered [6]. In Iran, Amiri Rad and Fallahi (2019) investigated three different external wall insulation materials and thickness of an office building. Investigation was carried out for Polyurethane, expanded polystyrene (EPS) and Rockwool, based on energy, environment and economy criteFria, using EnergyPlus software.

Results showed that the optimum thicknesses for the three mentioned insulation material are 8 cm, 20 cm and 7 cm, respectively [7]. Albizanti et al. (2022) numerically calculated the effect of associated building insulation costs on optimal thickness and payback period. Results showed that optimal insulation thickness was not effected by associated costs, unlike payback period that increased from 2.14 year to 4.63 year [8]. Dardouri et al. (2023) numerically simulated Phase change material (PCM), as an insulation material integrated with building envelope. Several PCM parameters; including melting temperature, PCM combination with other insulation materials were investigated in terms of energy savings in residential buildings in Tunisia. Results showed an energy reduction of 73.81% and 76.46% could be achieved under the optimum conditions of using PCM with simple and double wall buildings, respectively. This reduction was reflected in CO_2 reduction [9]. Al-Yasiri and Szabo (2023) modelled a combination of PCM and traditional expanded Polystyrene (EPS) as a building insulation material with different thicknesses to improve building thermal insulation. Results showed that combination of PCM-EPS thermally performed better than PCM alone, with an improvement in terms of maximum and average indoor temperature reduction by 143 % and 35 %, respectively [10]. On the other hand, Aboudh proposed an integrated Photovoltaic shading elements on a building south façade to enhance office occupants' thermal comfort. simulation results show a reduction of about 17.15% in the annually transmitted heat gains to the building.[11]

The importance of this study lays in reaching the building thermal and economic comfort, consequently reducing the electrical energy consumption due to the use of heating and cooling systems. Moreover, economic feasibility study on applying insulation in Libyan buildings is important, especially with the low current supported energy prices and changes might happen on future energy prices. Reducing heat loss of building will be a result of using optimized parameters for the thermal insulation such as: insulation thickness and density as well as the building insulated parts (walls and/or roof). a comparative study will be conducted using Energy Plus software with reference values of building energy consumptions from former study to the same building, where no insulation materials were used [12].

2. METHODOLOGY

EnergyPlus software is a building energy simulation software that used to model building energy consumption including: heating, ventilation, cooling, lighting and process loads [13]. Building characteristics and material properties are used as inputs to Energy Plus software for the studied cases.

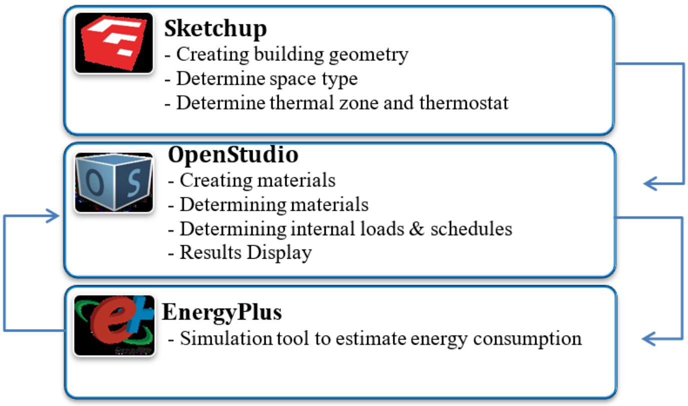

Figure 1. Building simulation workflow [12].

EnergyPlus software setup was dependent on the reference case with the addition of insulation to the studied building [12], as it will be mentioned in the next sections.

SketchUp was used to create building geometry, whereas OpenStudio was used to modify model properties: insulation materials, construction, occupancy, internal loads as well as schedules [14]. Then, EnergyPlus is used to perform an annual energy simulation [13]. Results obtained were presented in OpenStudio. Building simulation workflow is shown in Figure 1 [12].

2.1. Building characteristics

Figure 2 shows the Engineering Affairs Building (latitude 32° 815° N, longitude 13° 438° E), and the main entrance is facing the north. Building is a one ground floor with an area of 81m² (roof area) and 3 m height, where the total area of the external walls is about 123m². Building consists of four offices, each with an area of 16.33m² and four service rooms with an area of 3.23 m² each. The building has an annual energy consumption of about 6245 kWh [12], which is used as a reference case for comparison with the studied scenarios.

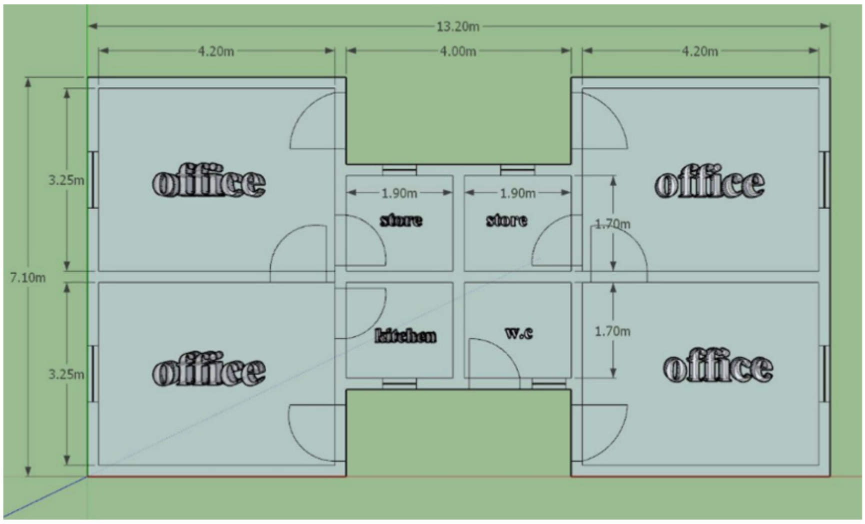

Figure 2. Engineering affairs building.

External doors in the building are five doors and changed from wood to metal insulation board and the total area is 10 m². Windows are changed from operable single glazing with 3 mm thickness, to operable double glazing with a thickness of 6 mm and air thickness of 12 mm. The total area of building external windows is about 4 m². Table 1 lists the properties of the proposed doors and windows materials.

Table 1. Properties of proposed doors and windows [14].

conductivity w/m.k	Density Kg/m³	Specific heat J/kg.k	Thickness cm	Window& door
-	-	-	0.6	window
0.131	600	1.63	5	External door (Slab doors)
45.28	7824	500	0.08	Ex door sheet metal
0.03	43	1210	2.54	Insulation board

The proposed structure of the external walls consists of an internal cement plaster, concrete block, cement plaster layer, an external thermal insulation; made of polystyrene with different thicknesses and densities, and an external cement plaster as shown in Table 2. The internal walls consist of cement plaster, concrete block and cement plaster, where no use of heat insulation.

Table 2. External walls construction material properties.

Conductivity W/m.k	Density Kg/m³	Specific heat J/kg.k	Thickness cm	External walls
0.72	1856	0.84	2	Plastering material
1.11	800	0.92	20	Concrete blocks
0.72	1856	0.84	2	plastering material
0.038	15, 25, 35	1.5	2.5, 5, 10	Ex. polystyrene
1.11	800	0.84	2	Cement plaster

9 wall insulation cases were studied, changing three different insulation thicknesses for each of three different densities, as shown in Table 3.

Table 3. Studied cases of insulation.

		Insulation Board density (kg/m³)		
		15	25	35
Insulation board thickness (cm)	2.5	1	2	3
	5	4	5	6
	10	7	8	9

Building roof consists of roof membrane, external polystyrene, Terrazzo, cement / lime, sand gravel aggregate concrete and limestone concrete. Roof construction properties are listed in Table 4.

Table 4. Roof construction material properties.

Roof	Thickness cm	Specific heat J/kg.k	Density Kg/m³	Conductivity W/m.k
Roof membrane	0.9	1.46	1121.29	0.16000
Ex. polystyrene	2.5,5,10	1.5	15,25,35	0.038
Terrazzo	2.5	0.79	2560	1.8
Cement /lime	3	0.88	1920	1.4
Sand gravel aggregate concretes	10	0.84	2240	1.3
Lime stone concrete	20	0.84	1920	1.1

2.2. Building Insulation studied scenarios

Three different insulating scenarios were studied, including insulating external walls only, roof only and external walls and roof. Insulation thickness and density were changed according to table 2, where the density is changing to three values and thickness is to three values for each density value.

2.3. Cost of thermal insulation (polystyrene)

Figure 3 shows the insulating material (Polystyrene) costs, including installation costs. The cost of insulating materials is determined by meters, and varies according to thickness (cm) and density (kg/m³). It clear from figure 2 that the cost ranges from 8.75 Libyan dinars (L.D)/m², for the thickness of 2.5 cm and density of 15 kg/m³ to 75 L.D/m², for the thickness of 10 cm and density of 35 kg/m³ and may reach up to 80 L.D/m², when additional cleaning costs is added. Mentioned costs will be added to the membrane and cement plaster costs, which are about 28 L.D/m^2 and 30 L.D/m^2, respectively.

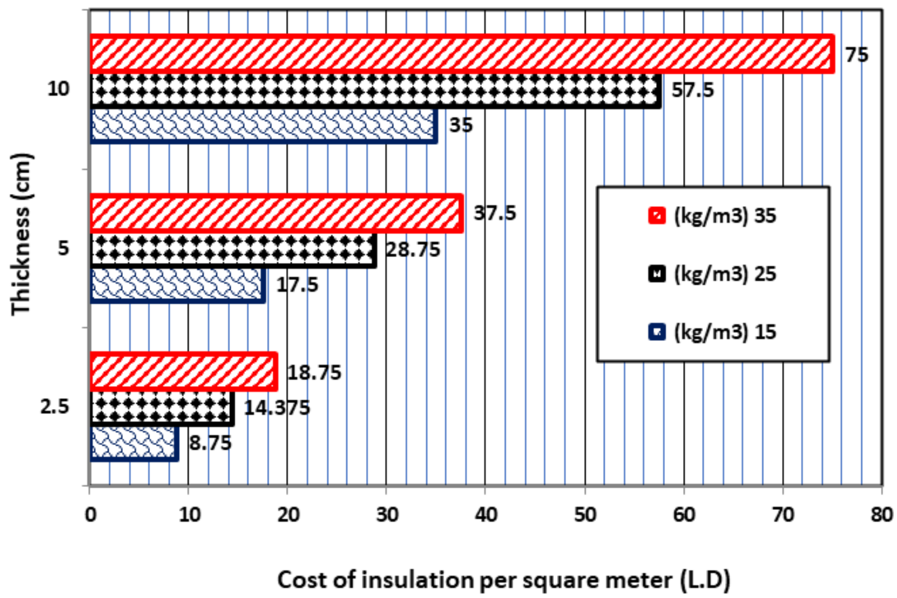

Figure 3. Cost of polystyrene material and installation.

To calculate the total building insulation cost for roof insulation scenario, each insulation thickness cost with membrane _including installation _ cost per square meter, was multiplied by the roof area (81 m^2). Also in wall insulation scenario, each insulation thickness cost with cement paster cost per square meter, was multiplied by the external walls total area (123 m^2). In the case of wall and roof insulation scenario, the external walls insulation thickness was proposed to be fixed at 5 cm, and the change was in roof thickness only to 2.5 cm, 5 cm and 10 cm. So, the total cost of this scenario was calculated depending on the average insulation thickness. The average insulation thickness was calculated for the walls by multiplying wall thickness by the area of external walls and for the roof by multiplying roof insulation thickness by the area of roof, gathering the two values and dividing on the total area roof and walls (204 m^2). The average insulation thickness in wall and roof scenario was 4 cm, 5 cm and 7 cm. Finally, the average insulation thickness cost per square meter for each case was multiplied by the total area of roof and walls.

2.4. Payback period

The payback period was calculated according to the energy saving (kWh/year) multiplied by three different tariff values to convert to money saving in Libyan dinar (L.D/year). Different electricity tariff values were determined by GECOL, depending on type of building (residential, commercial or industrial), as well as the amount of energy consumption [15]. Tariff value chosen for this study is (0.15 L.D/kWh), which the closest value among tariffs to the calculated tariff depending on the fuel price supported by the Libyan government (0.1732 L.D/kWh) as well as the tariff calculated depending on the real fuel price for the year 2021(0.9261 L.D/kWh). After that, total insulation cost for each case in the three scenarios was divided by the money saving (in L.D/ year) for that case.

2.5. Insulation percentage gain

As the polystyrene insulation material life cycle is over 50 years [16][17]. Insulation percentage gain or loss was calculated for the period of 50 years, which is the least expected building lifecycle [18]. Insulation percentage gain is calculated by the difference between net money saving (total money saving – total cost) for 50 years (in L.D) from each insulation scenario and the insulation total cost in percent.

3. RESULTS

3.1. Effect of insulation density on building energy consumption

Figure 4 shows the effect of insulation material density on energy consumption for the nine cases of three mentioned densities. It is clear that the insulation density has no significant effect on energy consumption, at fixed insulation thickness. For instance, at 2.5 cm insulation thickness, energy consumption is about 5281 kWh for the three densities of 15 kg/m^3, 25 kg/m^3 and 35 kg/m^3. While at 10 cm insulation thickness, energy consumption is about 4994 kWh for the same three densities. The decrease in energy consumption is as result of the increase in insulation thickness rather than insulation density. Consequently, the cheaper polystyrene cost with a density of 15 kg/m^3 was selected for the next energy consumption investigations.

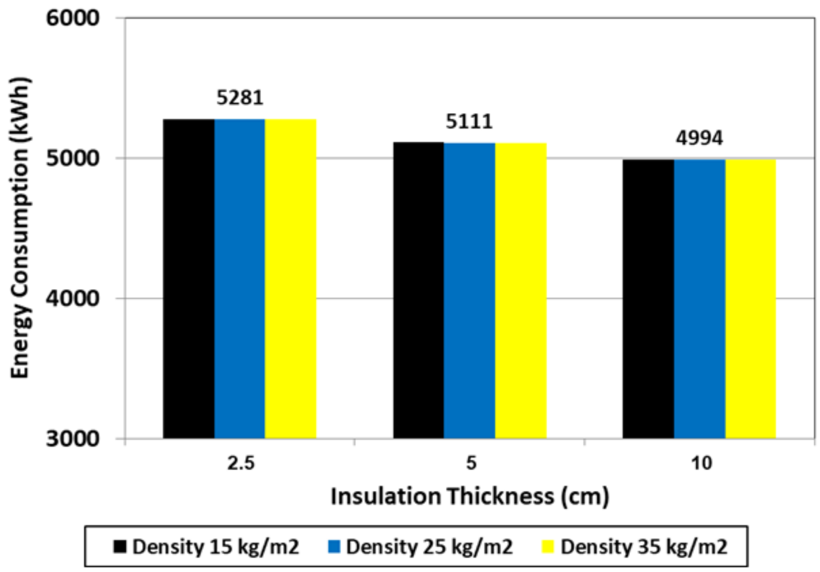

Figure 4. Effect of insulation density on building energy consumption.

3.2. Effect of insulation thickness on annual energy consumption

Figure 5 shows the effect of insulation thickness on energy consumption for with polystyrene density of 15 kg/m^3 and different thicknesses. It is clear from figure 5 that in the three mentioned scenarios the energy consumption decreases with the increase of polystyrene thickness. It shows that consumption drops from 6245 kWh when no insulation is used (reference case), to about 5544 kWh, 5281kWh and 4578, for the roof, walls and roof and walls insulation scenarios, at a thickness of 2.5 cm, respectively. In the case of 10 cm insulation thickness, energy consumption is continuing to decrease to reach about 5328 kWh, 4993 kWh and 4325, for scenarios, respectively.

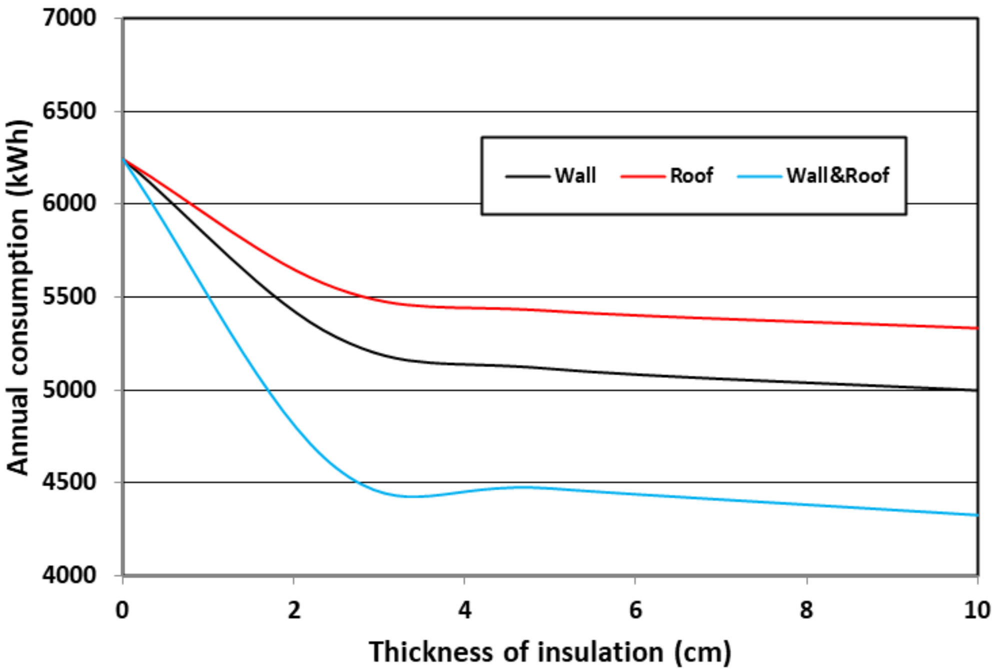

Figure 5. change of annual energy consumption with insulation thickness.

3.3. Annual energy saving

Figure 6 show the insulation annual energy saving (in kWh) at different insulating scenarios. It is clear that annual energy saving changes with the insulation method. the maximum annual energy saving reaches about 1920kWh, at walls and roof insulation scenario with roof thickness 10 cm (Avg. 7 cm). and decreases with decrease of insulation thickness to reach the minimum value at roof insulation scenario to about 701 kWh.

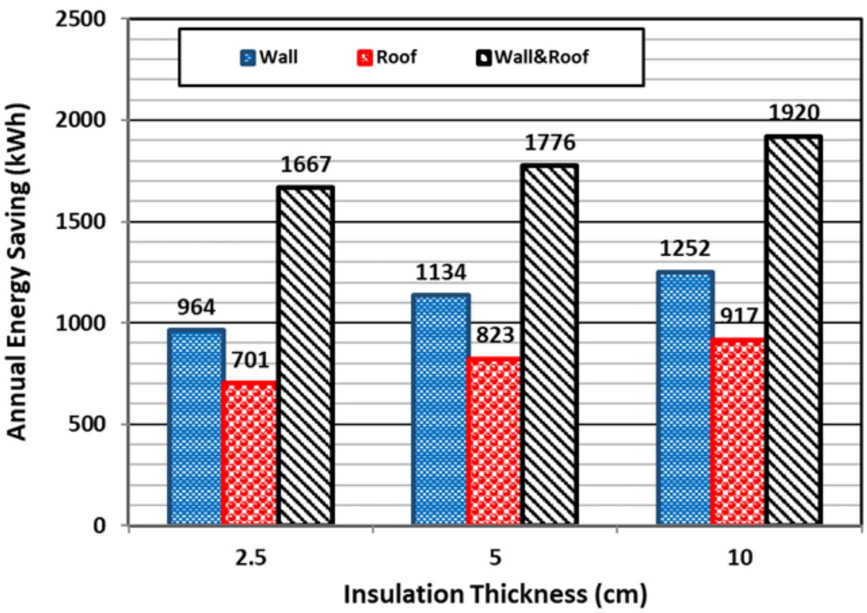

Figure 6. Building annual energy saving.

3.4. Insulation cost and money saving

Figure 7 shows the building insulation cost and money saving (in L.D), as well as the payback period for each thickness in the roof scenario. It is obvious that the insulation thickness has a significant effect on the insulation cost and money saving, where both increase with the increase of insulation thickness, as well as the payback period (in years). The roof insulation costs were 2977 L.D, 3686 L.D and 5103 L.D, at insulation thicknesses of 2.5 cm, 5 cm and 10 cm, respectively. On the other hand, at an electricity tariff of 0.15 L.D/kWh, the money savings were 105 L.D/year, 123 L.D/year and 138 L.D/year at insulation thicknesses of 2.5 cm, 5 cm and 10 cm, respectively. Money saving increases with the increase of electricity tariff, simultaneously, decrease the payback period. At 2.5 cm insulation thickness, money saving increased from 105 L.D/year at a tariff of 0.15 L.D/kWh, to 649 L.D/year at a tariff of 0.9261 L.D/kWh. This increase in tariff decreases the payback period for an insulation cost of 2977 L.D, from 28.3 years to 4.6 years for electricity tariffs of 0.15 L.D/ kWh and 0.9261 L.D/kWh, respectively.

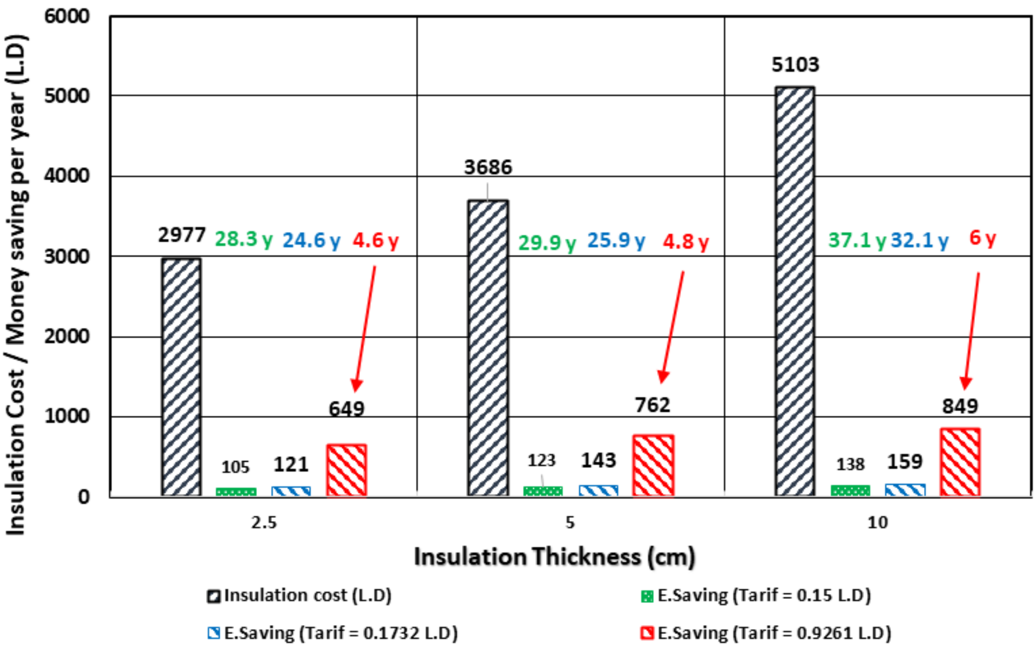

Figure 7. Insulation cost, money saving and payback period for each tariff in roof scenario.

The external wall insulation shown in Figure 8, insulation costs were 4766 L.D, 5843 L.D and 7995 L.D, at insulation thicknesses of 2.5 cm, 5 cm and 10 cm, respectively. At an electricity tariff of 0.15 L.D/kWh, the money savings increased from 145 L.D/year to 170 L.D/year and 188 L.D/ year at insulation thicknesses of 2.5 cm, 5 cm and 10 cm, respectively. On the other hand, at 2.5 cm wall insulation thickness, money saving increased from 145 L.D/year at a tariff of 0.15 L. D/ kWh, to 893 L.D/year at a tariff of 0.9261 L.D/kWh. The payback period in this scenario for an insulation cost of 4766 L.D, has decreased from 33 years to 5.3 years for electricity tariffs of 0.15 L.D/ kWh and 0.9261 L.D/kWh, respectively.

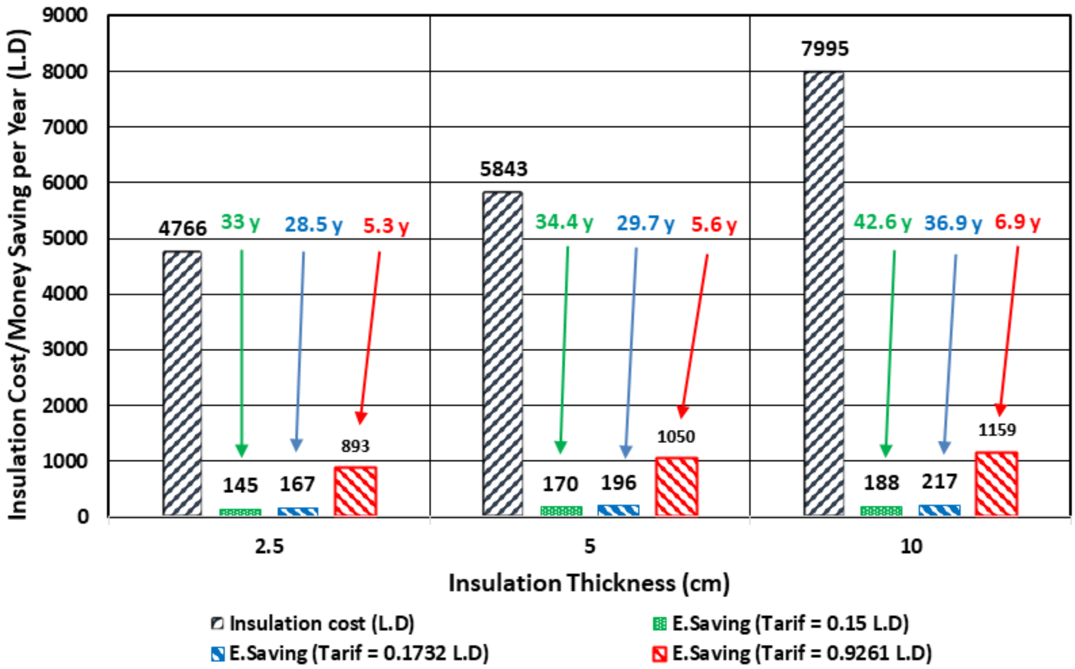

Figure 8. Insulation cost, money saving and payback period for each tariff in external walls scenario.

For the wall and roof insulation scenario shown in Figure 9, insulation costs were 8819 L.D, 9528 L.D and 10945L.D, at insulation thicknesses of 2.5 cm, 5 cm and 10 cm, respectively. In this scenario where the electricity tariff of 0.15 L.D/kWh, the money savings increased from 250 L.D/year to 266 L.D/year and 288 L.D/year at average insulation thicknesses of 4 cm, 5 cm and 7 cm, respectively. While at 4 cm wall insulation thickness, money saving increased from 250 L.D/year at a tariff of 0.15 L. D/kWh, to 1544 L.D/year at a tariff of 0.9261 L.D/kWh. The payback period for an insulation cost of 8819 L.D, has decreased from 35.3 years to 5.7 years for electricity tariffs of 0.15 L.D/ kWh and 0.9261 L.D/kWh, respectively.

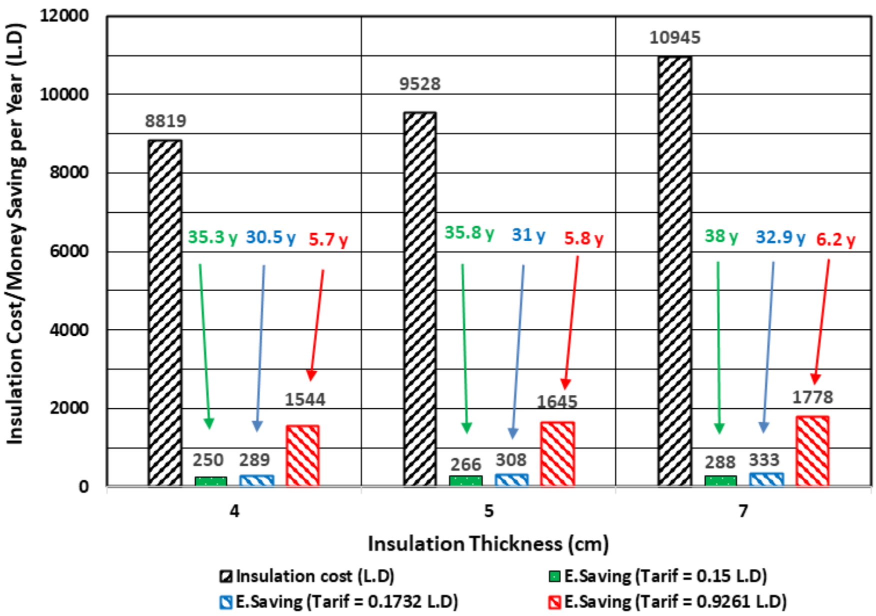

Figure 9. Insulation cost, money saving and payback period for each tariff in walls & roof scenario.

3.5. Insulation net money saving and percentage gain

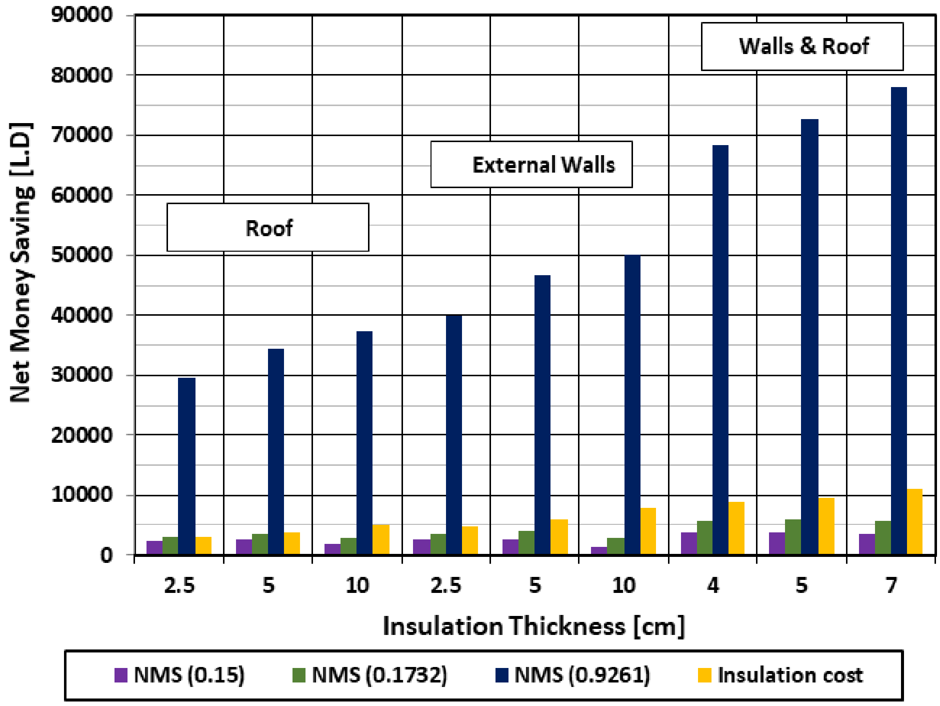

Figure 10. Net money saving of three scenarios with different insulation thickness.

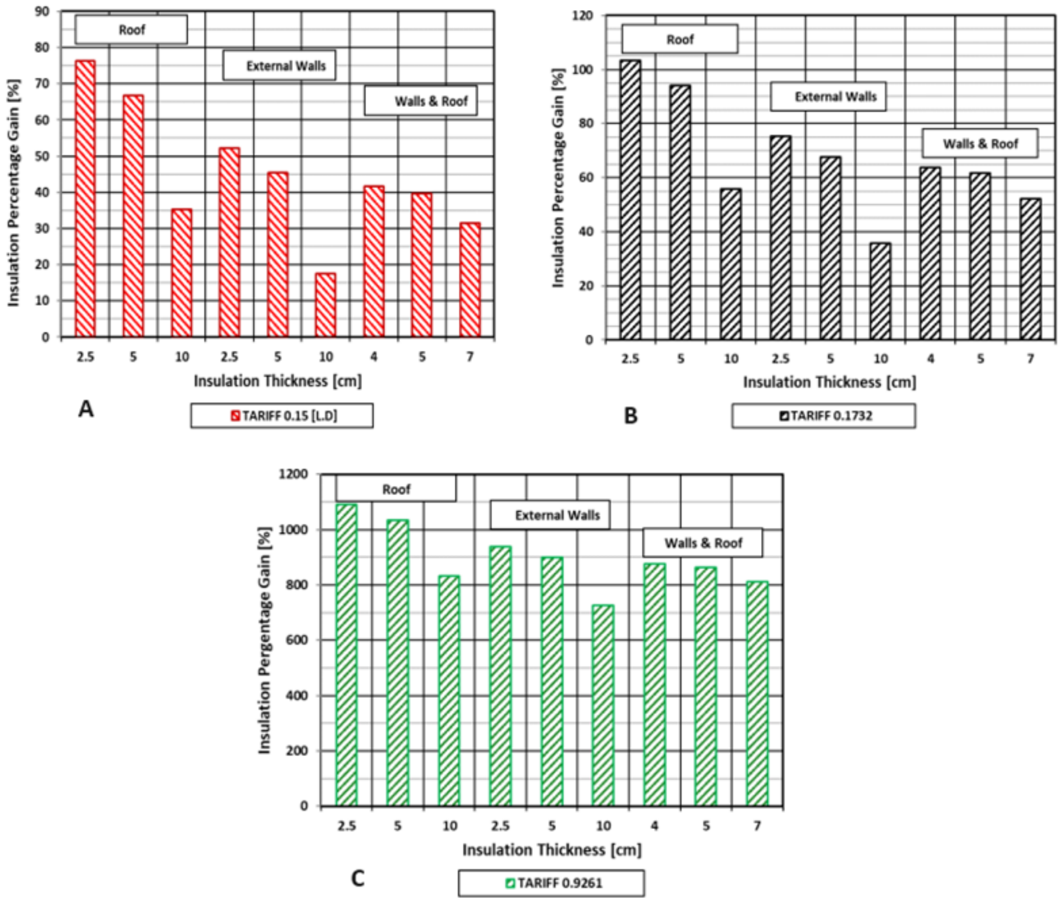

Figure 11. Insulation percentage gain at: (A) Tariff 0.15 L.D, (B) Tariff 0.1732 L.D and (C) Tariff 0.9261 L.D.

Figure 10 shows the three scenarios the net money saving for 50 years by the use of insulation depending on the energy tariff. It is clear that with increase of energy tariff the amount of money saved is more significant. For instance, using insulation thickness of 2.5 cm money saved with roof scenario increases from 2273 L.D with a tariff of 0.15 L.D/kWh to reach 29473 L.D with a tariff of 0.9261 L. D/kWh. Also, roof and wall scenario and insulation average thickness of 7 cm shows the most net money saving among scenarios reaching about 78000 L.D with a tariff of 0.9261 L.D/kWh. Simultaneously, the lowest money saving is the roof scenario and insulation thickness of 2.5 cm reaching about 29473 L.D with the same tariff.
Figure 11 shows the three insulation scenarios percentage gain (%), with different insulation thicknesses and energy tariffs for 50 years of building installation. In contrast with the net money saving, Figure 10 shows that the highest insulation percentage gain is achieved by the use of lower thickness (2.5 cm). The insulation percentage gain increases with the increase of energy tariff, to reach the highest values of 76 %, 103 % and1090 % at the roof scenario, 2.5 cm insulation thickness and energy tariffs of 0.15 L.D/kWh, 0.1732 L.D/kWh and 0.9261 L.D/kWh, respectively. While the lowest percentage gain values are of about 17.5 %, 35.7 % and 725 % at the wall scenario 10 cm insulation thickness and energy tariffs of 0.15 L.D/kWh, 0.1732 L.D/kWh and 0.9261 L.D/kWh, respectively.

4. CONCLUSIONS

Three different insulating scenarios were investigated using Energy-plus software, to study the effect of using expanded polystyrene boards on building energy consumption. The three scenarios include insulating roof, external walls, and roof and external walls. Three different polystyrene insulation thicknesses and densities were studied, Payback period, Polystyrene total cost, total and net money saving using insulation as well as the percentage gain were calculated for each case in the three investigated scenarios.
It is concluded that insulation density has no significant effect on energy consumption. Increasing insulation thickness decreasing significantly building energy consumption. Increasing insulation thickness increases net money saving and conversely decreases percentage gain. The most money saving scenario was with insulating building roof and external walls with average insulation thickness of 7 cm. on the other hand The highest percentage gain achieved was by insulating building roof with a thickness of 2.5 cm. the payback period of insulation total cost is significantly dependent on energy tariff that the longest payback period has decreased from 42.6 years to 6.9 years with energy tariffs of 0.15 L.D/kWh and 0.9261 L.D/kWh, respectively. These findings agree with Alghol et al [6] results that low energy tariff (current energy tariff) values economically are not cost effective regarding the payback period. Consequently, prices do not motivate residents to save energy with the use of thermal insulation unless actual energy prices are considered. Results of this study provides a clear path to the application of such insulations in this area, in terms of insulation design and expected cost and payback period.

Author Contributions: The first author's contribution was in the first idea of this research paper as well as in part of the simulation and data acquisition with the third author. Second author contributed in conception, design, data analysis and interpretation, as well as writing first draft. Revision, approval of final version and agreement for all aspects of the work related to its accuracy or integrity was for the three authors mentioned in this paper.
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Conflicts of Interest: The authors declare that they have no conflict of interest.

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